



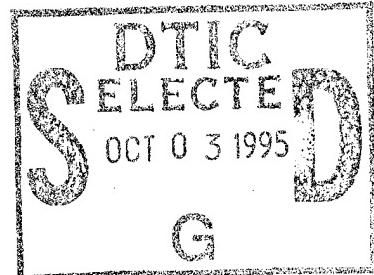
ESL-TR-92-12

DEMONSTRATION OF NONCYANIDE
STRIPPERS TO REPLACE CYANIDE
STRIPPERS, PART 1 OF 2

M.D. ARGYLE, R.L. COWAN, R.V. FOX,
G.S. GROENEWOLD, S.K. JANIKOWSKI,
R.S. MARTINEZ, D.A. NOWERS, A.
NOWERS, M.T. SAYER

IDAHO NATIONAL ENGINEERING
LABORATORY
EG&G IDAHO, INC.
IDAHO FALLS, IDAHO 83415-2050

MARCH 1995



FINAL REPORT

JANUARY 1990 - SEPTEMBER 1990

APPROVED FOR PUBLIC RELEASE:

DTIC QUALITY INSPECTED 6

ENVIRONICS DIVISION
Air Force Civil Engineering Support Agency
Civil Engineering Laboratory
Tyndall Air Force Base, Florida 32403



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REPORT DOCUMENTATION PAGE

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Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

| | | | |
|---|--|--|----------------------------|
| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED | |
| | March 1995 | Final | |
| 4. TITLE AND SUBTITLE | | 5. FUNDING NUMBERS | |
| Demonstration of NonCyanide Strippers to Replace Cyanide Strippers, Part 1 of 2 | | DE-AC07-76ID01570 | |
| 6. AUTHOR(S) | | | |
| M.D. Argyle, R.L. Cowan, R.V. Fox, G.S. Groenewold, S.K. Janikowski, R.S. Martinez, D.A. Nowers, A. Nowers, M.T. Sayer | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| Idaho National Engineering Laboratory EG&G Idaho, Inc. Idaho Falls, Idaho 83415-2050 | | EGG-WTD-10087 | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER | |
| HQ AFCESA Tyndall AFB, FL 32403 | | ESL-TR-92-12 Part 1 of 2 | |
| 11. SUPPLEMENTARY NOTES | | | |
| Prepared for the United States Air Force through the U. S. Department of Energy. | | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT | | 12b. DISTRIBUTION CODE | |
| Unlimited Distribution | | | |
| 13. ABSTRACT (Maximum 200 words) | | | |
| <p>This report is divided into parts. Part 1 consists of the front matter, text, and Appendixes A through F, pages 1-204. Part 2 consists of Appendixes G through K, pages 205-361. The objective of the work described in this report was to develop and demonstrate an improved means to replace cyanide containing metal stripping solution in the plating shops at the Air Logistics Centers. During the program, 35 commercial strippers, 3 Air Force process solutions, and a generic nickel stripper were tested. First, these strippers were evaluated on a laboratory scale. If a stripper proved worthwhile in the laboratory, it then was scaled up in a field test. The next step was to implement the most worthwhile products into the plating shop at Kelly AFB. Two strippers, B-9 Nickel Stripper and Rostrip 999-sp Electrolytic Silver stripper, have been successful and implemented into the plating shop at Kelly. These strippers will effectively replace the cyanide stripping processes formerly used by the Air Force.</p> | | | |
| 14. SUBJECT TERMS | | 15. NUMBER OF PAGES | |
| Plating Strippers (U), Red Water Problem (U) Noncyanide Strippers (U), Electroless Nickel (U) Biodegradability and compatibility testing (U) | | | |
| | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

19950928041

PREFACE

This report was prepared by Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho 83415-2050, DE-AC07-76ID01570, for the U.S. Department of Energy (DOE) and the Air Force Civil Engineering Support Agency (AFCESA), 139 Barnes Drive, Suite 2, Tyndall Air Force Base, Florida 32403-5319.

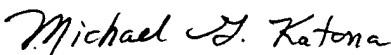
This report presents the results of an Idaho National Engineering Laboratory (INEL) study and demonstration to eliminate and replace cyanide containing metal stripping solutions in the plating shops at Air Logistics Centers. During the testing program, 35 commercial strippers, 3 Air Force process solutions, and a generic nickel stripper were tested. First, these strippers were evaluated on a laboratory scale. If the stripper proved worthwhile in the laboratory, it was then scale-up to a field test. The follow-on testing beyond successful field testing was to implement the most worthwhile products into the Air Logistics Centers plating shops. Two strippers were successfully implemented into the plating shop at Kelly AFB. These two strippers will effectively replace the cyanide stripping processes formerly used by the Air Force.

This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service, where it will be available to the U. S. Government Agencies only because of the proprietary nature of the research.

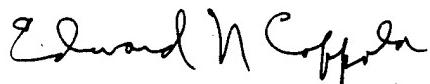
This report has been reviewed and is approved for publication.



PHILLIP P. BROWN, 1LT, USAF, BSC
Environmental Engineer



MICHAEL G. KATONA
Chief Scientist



EDWARD N. COPPOLA, Maj, USAF
Chief, Environmental Compliance
Division



NEIL J. LAMB, Colonel, USAF, BSC
Chief, Environics Directorate

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EXECUTIVE SUMMARY

OBJECTIVE

The objective of the Demonstration of Noncyanide Metal Strippers to Replace Cyanide Strippers (DNCYS) Program is to implement the technologies needed to completely remove the cyanide containing process solutions and eliminate the subsequent generation of cyanide bearing wastes at Air Logistic Command Centers (ALCs). The preceding program titled Noncyanide Metal Strippers to Replace Cyanide Strippers (NCYS) was directed toward replacement of cyanide strippers, while present efforts focus on implementing those technologies which will enhance the performance of these new strippers and help to achieve waste minimization. This includes development and implementation of generic strippers, waste treatment technologies, and process enhancements.

BACKGROUND

The program to replace cyanide containing metal stripping solutions in the plating shop at Kelly AFB has moved into the demonstration phase. During the preceding program, 35 commercial strippers, 3 Air Force process solutions, and a generic nickel stripper were tested. First, these strippers were evaluated on a laboratory-scale using 250 to 1000 mL of solution and the manufacturers' recommended operating parameters. If a stripper proved worthwhile in the laboratory, it was then scaled-up in field tests to volumes of 75 to 3800 liter (20 to 100 gallon). Field tests were used to optimize variables such as pH, temperature, longevity, metal loading, and regeneration. The step beyond successful field testing was to implement the most worthwhile products into the plating shop at Kelly AFB.

The major organic components of each noncyanide metal stripping product targeted for implementation were identified. The constitutive biodegradation ability of the activated-sludge from the Kelly AFB Industrial Wastewater Treatment Plant was tested using individual organic chemicals as substrates. Ethylenediamine and nitroaromatic corrosion inhibitors were the first components targeted for testing because they represent the major organic constituents of a number of noncyanide metal strippers recommended for implementation. Constitutive biodegradation ability testing was completed for ethylenediamine. The test determined that the activated-sludge was not currently acclimated to ethylenediamine.

The inherent biodegradability of ethylenediamine was tested using a microbial population derived from the Kelly AFB Industrial Wastewater Treatment Plant activated-sludge. The results of the test determined that the activated-sludge contained three different microbial strains which could acclimate to and biodegrade ethylenediamine.

Experiments conducted this year (FY-91) determined the inherent biodegradability of the metal stripping product CLEPO 204 and the compatibility of ethylenediamine and CLEPO 204 with the existing wastewater treatment system. Ethylenediamine was used as a substrate in mono-component compatibility experiments. A waste solution of CLEPO 204 (containing ethylenediamine, *m*-nitrobenzoate, and an unknown colored component) was the

first product used as a substrate for the multi-component compatibility experiments.

SCOPE

During Phase I of the DNCYS Program, two commercial strippers were implemented into the plating shop at Kelly AFB. These included one commercial nickel stripper (Metalx, Inc. B-9 Nickel Stripper) and one electrolytic silver stripper (McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper). Electrochemical tests were used to aid in the development of an electroless nickel stripper. Field tests were performed on a generic nickel stripper which successfully stripped both electrolytic and electroless nickel coatings. Library investigations were used to help identify the chemical specie(s) responsible for the "Red Water" problem.

Biodegradability and compatibility experiments were performed on CLEPO 204 and one of its major organic components ethylenediamine. The species responsible for the intense coloration in spent CLEPO 204 solutions was tested for inherent biodegradability.

METHODOLOGY

The evaluation of commercial and generic noncyanide stripping solutions used sample coupons which were representative of the metals routinely processed in Air Force plating shops. The plate and basis metal stripping or corrosion rates could then be measured using a weight loss method without risking destruction of actual aircraft parts. The weight lost during the stripping process revealed how well the solutions stripped the various plate metals and whether they were corroding the basis metals at an unacceptable rate. Visual inspection of the test coupons also yielded information about the types of corrosion (e.g., pitting) that may have occurred on the basis metals.

The laboratory tests (jar tests) involved only small quantities of stripping solution -- generally less than one liter. Standard electrochemical tests that determine corrosion rates were used to test potential electroless nickel strippers for effectiveness. Later these solutions were tested using the weight-loss procedure mentioned above. In the field tests, the same type of experiment was performed with the exception that a larger volume of stripping solution was used: the experiments were contained in either 38 or 57 liter (10 or 15 gallon) process tanks, heated, and mechanically agitated to more closely resemble conditions within Air Force plating shops. Field testing also involved tests to determine optimum pH and temperature, maintenance requirements, regeneration procedures, effects of metal loading, and the lifetime of the solutions.

Implementation tests were conducted to monitor the strippers in service at the plating shop. While the noncyanide stripping solutions were being used to strip parts in the plating shop, occasional checks for the stripping rate was made using the same test procedures mentioned above with metal coupons.

Biodegradability tests, using ethylenediamine and spent CLEPO 204 solutions, were conducted in shake-flasks. The tests involved monitoring

biomass production and the loss of substrate over time. Controls were run to validate the test results. Inherent biodegradability experiments using the nitroaromatic corrosion inhibitor as a substrate were not performed because the nitroaromatic species present in CLEPO 204 was improperly identified (see RATIONALE section of this report for explanation).

Compatibility tests were conducted in bench-scale continuous-flow bioreactors using ethylenediamine and spent CLEPO 204 as substrates. Process wastewater and activated-sludge from the Kelly AFB Industrial Wastewater Treatment Plant was used in the tests to help mimic existing conditions. Compatibility tests were not conducted using the nitroaromatic component of CLEPO 204 for the same reason as mentioned above (see RATIONALE section of this report for explanation).

TEST DESCRIPTION

Stripping test solutions were prepared in accordance with instructions from commercial vendors or Air Force Technical Orders. Laboratory metal stripping tests utilized solution volumes of 250 to 1000 mL while the capacity for the process tanks used in the field tests were either 38 or 57 liter (10 or 15 gallon). The plate and basis metal coupons were immersed in the stripping solution, kept at a constant temperature, and stirred. Field tests optimized the process operating parameters: temperature, pH, longevity, metal loading, and regeneration. The plate metal stripping performance and basis metal corrosion inhibition was evaluated from weight loss data and microscopic analysis of the coupons after the tests. The immersion tests utilized the following times: 1 hour for electrolytic nickel, 2 hour for electroless nickel, and 24 hours for basis metal tests. The electrolytic tests were much shorter in duration: 15 minutes for silver and 1 to 3 hours for the basis metals. Electrochemical techniques were used to evaluate generic nickel strippers prior to laboratory testing. Standard corrosion techniques and software was used in the analysis. The preferred techniques used for this year's work were Anodic Potentiodynamic Polarization and Tafel analysis.

Shake-flask experiments are designed to provide data as to the inherent biodegradability of the substrate being tested. The shake-flask studies provide adequate time for operon induction, enzyme production, and biomass proliferation in the presence of a recognizable substrate. These studies are follow-up experiments to the six hour tests which were designed to demonstrate constitutive biodegradation abilities. These experiments were conducted in the laboratory using 250 mL shake-flasks containing a minimal salts media, a microbial population derived from the Kelly AFB activated-sludge, and mono-component or multi-component carbon sources. The shake-flask tests were conducted at room temperature with shaking for 72 hours.

The compatibility tests used conditions which were representative of those conditions currently used at the Kelly AFB Industrial Wastewater Treatment Plant. Treatment Plant process wastewater and activated-sludge was used in a 4.5 liter aerated, continuous-flow bioreactor. Fluid retention times, biomass concentrations, dissolved oxygen concentrations, and mean cell retention times reflected those conditions which currently existed at the Treatment Plant. Influent and effluent Total Organic Carbon, Chemical Oxygen Demand, nitrate, nitrite, ammonia, sulfate, phosphate, substrate, and phenol

concentrations were monitored over time. Activated-sludge suspended solids concentration, settling velocity, volume index, and oxygen consumption rate were also monitored over time. The substrates used for testing were added to the influent reservoirs. The substrate (mono- or multi-component) concentration was initially low, but was increased over time as effluent monitoring indicated successful biodegradation. The microbial population distribution of each bioreactor was determined by standard microbial isolation and plate count procedures. Microbial identification was done by fatty acid analysis.

RESULTS

Two strippers were successfully implemented into the plating shop at Kelly AFB (Metalx, Inc. B-9 Nickel Stripper and McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper). The B-9 works well for removal of electroless nickel and also removes electrolytic nickel plates. Rostrip 999-SP has proven an acceptable replacement for the Air Force's Electrolytic Cyanide (C-101) process for silver stripping applications. Only the generic nickel stripper was field tested this year. This stripper has yielded exceptionally fast stripping rates (typically greater than 2.5 mil/hr for electrolytic nickel) and has withstood an incredible amount of nickel loading (5 ounces per gallon) while still maintaining an acceptable stripping rate of over 1 millinch per hour. It has also shown the ability to be regenerated by addition of starting reagents. The generic stripper is also being recommended for electroless nickel stripping over the other two alternative strippers that were developed this year. The first was glycine based and was similar to Metalx B-9. The other was slightly inferior, but could serve as a replacement for B-9, and was citric acid based. Addition of a small amount of ethylenediamine to electroless nickel strippers was shown to enhance nickel stripping rates.

The two major organic components of CLEPO 204 waste solutions (ethylenediamine and *m*-nitrobenzoate) were successfully biodegraded during multi-component compatibility testing. Although mono-component constitutive biodegradation ability, inherent biodegradability, and compatibility tests were not conducted on *m*-nitrobenzoate it was fortunately determined that in this one situation these tests could be skipped because the nitroaromatic was successfully biodegraded in the multi-component compatibility experiment.

An activated-sludge contact time of 5.3 hours was found to provide very poor treatment efficiency. A contact time of 8.3 hours was found to provide acceptable treatment of CLEPO 204 waste solutions. CLEPO 204 biodegradation by-products included excessive amounts of ammonia and nitrate. The intensely colored component in the waste CLEPO 204 solution could not be biodegraded under the experimental conditions used.

CONCLUSIONS

Two strippers, B-9 Nickel Stripper and Rostrip 999-SP Electrolytic Silver Stripper, have been successfully implemented into the plating shop at Kelly AFB. These strippers will effectively replace the cyanide stripping processes formerly used by the Air Force (C-101 and C-106). With the inclusion of these strippers, the goal of complete removal of cyanide strippers from the plating

shop at Kelly AFB will become a reality. A generic nickel stripper has been field tested and has shown better stripping rates, longevity, loading, and regeneration properties than any other stripper we have previously tested. The generic stripper also showed acceptable stripping rates for electroless nickel coatings with low to medium phosphorus content. The development work to create an electroless nickel stripper only yielded stripping solutions that were comparable to Metalx B-9, not better.

Compatibility testing of CLEPO 204 waste solutions has shown that this product is not compatible with the existing waste treatment facilities due to excessive effluent ammonia and nitrate as by-products of biodegradation. Also of concern is the fluid retention time required for treatment of noncyanide stripper wastes which contain ethylenediamine and/or *m*-nitrobenzoate. A fluid retention time of less than 8 hours results in very poor treatment. The "red water" component could not be biodegraded under existing Kelly AFB Industrial Wastewater Treatment Plant conditions and yielded an effluent which was too highly colored for release into the environment.

RECOMMENDATIONS

The implementation work completed this year should be distributed among the other ALCs. Metalx, Inc. B-9 Nickel Stripper and McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper should continue to be used at Kelly AFB and incorporated into other facilities. The generic nickel stripper should be implemented for both electrolytic and electroless (low to medium phosphorus content) nickel stripping applications. This recommendation is being made since the generic stripper was almost as good for stripping electroless nickel as Metalx B-9.

Biodegradability and compatibility testing of other noncyanide metal strippers targeted for implementation should continue. These tests should be conducted using both mono-substrate and multi-substrate conditions. The colored component associated with CLEPO 204 waste solutions needs to be identified, characterized, and a method developed to destroy it. Pilot-scale testing of CLEPO 204 waste is not recommended until the colored component can be degraded. Pilot-scale testing of mono-components (ethylenediamine) is not recommended because these components do not constitute actual conditions expected at the Kelly AFB Industrial Wastewater Treatment Plant. Full-scale treatment of waste solutions containing ethylenediamine and/or *m*-nitrobenzoate is not recommended for the Kelly AFB Industrial Wastewater Treatment Plant because the treatment plant cannot achieve the proper fluid retention time required and because of excessive nitrate and ammonia which are generated as by-products of biodegradation. An evaluation of the Kelly AFB Industrial Wastewater Treatment Plant is recommended because it has been observed that the plant is operating at a capacity which exceeds its treatment capabilities. It is also recommended that an evaluation of waste disposal methods at Kelly AFB be conducted because it has been observed that incompatible and undesirable chemicals are frequently being discharged to the Industrial Wastewater Treatment Plant which cause biological treatment system upset and failure. Finally, it is recommended that waste noncyanide metal stripping solutions be biologically treated in the pilot-plant facility.

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GLOSSARY OF TERMS

Acclimation

In terms of biodegradation: The time required for a substrate to be catabolized by a microorganism. Acclimation is characterized by the lag growth phase, and the catabolic response of the microorganism to the presence of a new but recognizable (usable) substrate.

Activated-sludge

A mixed culture of microorganisms cultivated on organic substances present in wastewaters under non-sterile conditions.

Activators

Chemicals present in a process solution that enhance the action of the main ingredient(s).

Basis metals

Substrate materials or parts, the underlying parts from which plate metals are stripped during refurbishment activities.

Biodegradation

The biological transformation of an organic molecule from a complex form to a more simple form. Complete biodegradation results in the formation of carbon dioxide and water.

Catabolic response

A cellular response which leads to biodegradation of a substrate.

Cathode

The electrode at which reduction occurs. In electroplating processes, the part to be plated is made cathodic.

Chemisorption

The act of chemically bonding to a surface, similar to adsorption but with stronger interaction.

Compatibility

Capable of orderly, efficient integration and operation with other elements in a system (e.g., the Kelly AFB IWTP).

Complexing agent

Used in this text to denote a chemical which coordinates strongly with metal ions and may increase their solubility.

Constitutive biodegradation

The ability to biodegrade an organic molecule using enzymes permanently present in a cell.

Corrosion inhibitors

Chemical agents added to process solutions for the purpose of inhibiting or preventing corrosion, etching, or removal of particular metals. These inhibitors may function on one or more different metals and are chosen carefully for specific applications.

Electroanalytical

Refers to an analysis technique requiring the careful monitoring of voltage/current relationships in test solutions.

Electroless deposition

The process of chemically depositing, by immersion, a metal coating onto a substrate without the use of an applied current.

Electroless nickel

In this report, a phosphorus nickel coating obtained from electroless nickel plating solutions containing hypophosphite reducing agent.

Electrolytic

A process requiring an electric potential and current flow.

Electrolytic deposition

The process of depositing a metal coating onto a part using electricity (electroplating).

Electrolytic nickel

In this report, refers to a "sulfamate" nickel. This is a coating obtained by electrolytic deposition from a nickel sulfamate solution.

Immersion

The act of dipping a part into a process solution and implying that no further action is required to initiate and complete the desired effect.

Inducible biodegradation

The ability to biodegrade an organic molecule using enzymes synthesized only in the presence of a recognizable (usable) substrate.

Inherent biodegradability

Those physical-chemical properties of an organic molecule which allow it to be susceptible to enzyme mediated chemical transformation.

Low alloy steel

Those steel alloys containing less than roughly 8 percent (by weight) alloying agents and impurities. This includes iron, malleable, and machinable steels as well as high strength steels, carbon steels, spring steels, and others.

Metal stripping

The process of removing a plated metal coating from any number of substrate materials.

Nitroaromatics

Organic chemicals containing a benzene ring substituted with a nitro-group.

Oxidizing agent

An agent which causes a chemical oxidation of another species, usually through a transfer of electrons onto the oxidizing agent.

Passivation

A term to describe the resistance to corrosion that a metal develops when electrically charged or in contact with an oxidizing agent or corrosion inhibitor.

Plate metals

Those metals commonly coated onto substrates by electrolytic or electroless deposition, spray coating, etc.

Recalcitrance

The inherent resistance of a chemical substance to any degree of biodegradation.

Red water

A term which refers to the colored wastewaters resulting from spent cleaning and stripping solutions.

Regeneration

The process of restoring the effectiveness of a stripping solution.

Specificity

The preference of a chemical to attack, adsorb on, or react with only a select group of chemicals, metals, or materials.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

| | |
|---------------------|--|
| AFB - | Air Force Base |
| AFTO - | Air Force Technical Order |
| Ag - | Silver |
| AgCl - | Silver Chloride |
| Ag ₂ O - | Silver Oxide |
| AMP - | Analytical Module Pump |
| ASTM - | American Society for Testing and Materials |
| ATP - | Adenosine Triphosphate |
| °C - | degree Centigrade |
| cm - | centimeter |
| COD - | Chemical Oxygen Demand |
| DAP - | Diaminopropionic acid |
| DNCYS - | Demonstration of Noncyanide Strippers to Replace Cyanide Strippers |
| DO - | Dissolved Oxygen |
| e.g. - | for example |
| E _{0c} - | Rest potential, zero-current potential, or corrosion potential |
| E _{corr} - | see E _{0c} |
| EPA - | Environmental Protection Agency |
| °F - | Degree Fahrenheit |
| FTF - | Field Test Facility |
| FY-() - | Fiscal Year |
| g - | gram |
| HPLC - | High Performance Liquid Chromatography |
| IC - | Ion Chromatography |
| ICP - | Inductively Coupled Plasma emission spectroscopy |
| i.e. - | in explanation |
| in - | inch |
| INEL - | Idaho National Engineering Laboratory |
| IWTP - | Industrial Wastewater Treatment Plant |
| JP4 - | Jet Propellant 4 |
| KCl - | Potassium Chloride |
| μL - | microliter |
| LAS - | Low Alloy Steel |
| m- - | meta- isomer |
| μm - | micrometer |
| mg - | milligram |
| MGD - | Million Gallons per Day |
| mL - | milliliter |
| MLSS - | Mixed Liquor Suspended Solids |
| mMolar - | 10 ⁻³ Molar |
| MSDS - | Material Safety Data Sheet |
| NADPH - | Nicotinamide Adenine Dinucleotide Phosphate |
| NCYS - | Noncyanide Strippers to Replace Cyanide Strippers |
| Ni-Cad - | Nickel-Cadmium deposit |
| Ni-P - | Electroless nickel plates |
| Ni-P* - | Electroless nickel coupons obtained during FY-90 |
| Ni-P** - | Electroless nickel coupons obtained during FY-91 |
| Ni-S - | Electrolytic nickel plates |
| NPDES - | National Pollution Discharge Emission Standards |
| PARC - | Princeton Applied Research Corporation |

pg. - page
pH - potential of Hydrogen
ppm - parts per million
PVC - Polyvinyl Chloride
R&D - Research and Development
RCRA - Resources Conservation and Recovery Act
redox - Reduction/Oxidation
ref. - Reference
SOUR - Specific Oxygen Uptake Rate
SS - Stainless Steel
SSV - Sludge Settling Velocity
SVI - Sludge Volume Index
TBAOH - Tetrabutylammonium hydroxide
TKN - Total Kjeldahl Nitrogen
T.O. - Technical Orders
TOC - Total Organic Carbon
TSP - Trisodium Phosphate
UV - Ultraviolet
USAF - United States Air Force
YSI - Yellow Springs Instruments, Inc.

SECTION I INTRODUCTION

A. OBJECTIVE

The objective of the Demonstration of Noncyanide Strippers to Replace Cyanide Strippers Program (DNCYS) is to demonstrate those commercial metal stripping processes which eliminate the use of cyanide containing process solutions. This will eliminate the bulk of cyanide bearing wastes generated from stripping activities at Air Force Facilities. This program specifically addresses those technologies supporting the replacement of cyanide metal strippers. The technologies currently in place have previously been evaluated for the effects which replacement or alteration would have on both upstream and downstream processes. This was done to ensure minimal impact on existing operations, and incorporated the development and implementation of technologies that reduce wastes, generate treatable wastes, or generate wastes that can be disposed of in an environmentally compliant manner.

This report addresses the work performed during the past year (Phase I, FY-91) of the Demonstration of Noncyanide Metal Strippers Program. The work performed in previous years (mostly developmental) under the Noncyanide Strippers to Replace Cyanide Strippers Program (NCYS) is discussed in detail in the Final Reports from Phases I, II, and III of the NCYS Program (refs. 1-3), and is also summarized in the background section of this report.

Although the DNCYS Program primarily deals with the demonstration of previously developed noncyanide metal stripper technologies and support technologies, research and development tasks are ongoing. The research and development efforts for the DNCYS Program have the following objectives:

1. To continue to test acceptable commercial noncyanide nickel and silver strippers for implementation.
2. To develop a biological waste treatment method which can be used for destruction of the organic constituents in noncyanide strippers.

3. To test new in-house "generic" noncyanide nickel strippers and make recommendations for their implementation.

Ongoing research and development efforts ensure a continuous supply of useful technologies by further development of new products and methodologies, and by improvement of existing products and methodologies. This approach also makes successful implementation of these products and methodologies more likely to be realized.

B. BACKGROUND

The United States Air Force (USAF) operates electroplating facilities for maintenance and overhaul of engine and airframe components. These facilities combine the organization and efforts of skilled workers with literally hundreds of technologies and tens of thousands of process steps. These maintenance and refurbishing activities are extensive, comprehensive, and on a massive scale.

At the time this program started, large amounts of cyanide solutions were used in metal refinishing operations. These included solutions to strip plate metals and other surface coatings from aircraft parts (strippers), to clean and remove smut from parts in preparation for electroplating (cleaners), and to electroplate metals onto parts (plating solutions). Each of these have a limited lifetime and eventually need replacement and disposal. At the start of FY-88, the metal stripping solutions and contaminated rinse waters comprised nearly 75 percent of the aqueous wastes generated in metal finishing operations. These wastes contained cyanide and toxic metals while the remaining waste cyanide containing solutions came from cleaning and plating operations.

Cleaning solutions use cyanide for the removal of rust, scale, and smut. They become saturated with metals and other contaminants until no longer effective and eventually require replacement. These cleaning wastes comprised roughly 5 to 10 percent of the aqueous, cyanide and heavy metal containing wastes generated in metal-finishing operations. The remaining contributors to

the cyanide waste problem were those solutions used in metal plating processes. Plating solutions become contaminated over time from drag-in of contaminants and decomposition of bath constituents. Eventually, the plating quality becomes so poor that the solution must be replaced. These plating wastes contributed the remaining 15 to 20 percent of the aqueous cyanide wastes generated in metal-finishing operations.

The treatment of these heavy metal-bearing cyanide wastes is by no means a straightforward process. These spent solutions can have high concentrations of both cyanide and heavy metals. Unfortunately, these solutions cannot be directly treated at the Industrial Wastewater Treatment Plant (IWTP) due to the toxic effects of cyanide and heavy metals on the biological treatment system. Most of the metals may be removed from these solutions using standard technologies including ion-exchange, precipitation, or sodium sulfide/ferrous sulfate precipitation (refs. 4,5). However, those metals complexed to cyanide are not readily removed due to the strong complexing nature of the cyanide ligand and the high solubility of the complexes. Therefore, the cyanide must be destroyed prior to metals precipitation and/or biological treatment to destroy the organics. Cyanide solutions may be destroyed using treatment processes that use chlorine gas or sodium hypochlorite in alkaline solutions (ref. 6). The efficiency of this cyanide destruction process is dependent upon the metals content of the solution. Many metals, especially iron, form cyanide complexes that are extremely resistant to this oxidative destruction. This complexed cyanide, although toxicologically innocuous, may still give analytical cyanide concentrations too high to allow for discharge of the treated solution directly into the environment. This results in a "Catch 22" situation for the treatment of heavy metal bearing cyanide wastes; since the heavy metals cannot be precipitated in the presence of cyanide, and the cyanide cannot be destroyed in the presence of many heavy metals.

Cyanide strippers have been used commercially to strip a large variety of plate metals and other surface coatings from a number of metallic and nonmetallic substrates. The resistance encountered when attempting to substitute these cyanide stripping solutions can be explained by the years of reliable service and familiarity that experienced workers have with these cyanide solutions.

However, the Air Force has committed themselves to removal of these cyanide processes from their operations. This is due to worker safety and waste disposal problems associated with the use of cyanide solutions. The spent solutions and sludges containing cyanide are hazardous wastes and are a significant part of the total electroplating waste generated at the ALCs (ref. 5). Human exposure to cyanide in any form poses great health risks with cyanide able to enter the human body through any of the following routes: a) inhalation of dusts, b) inhalation of the lethal gas formed by contact with acids, c) direct absorption through the eyes, mouth, nose, cuts and sores, or d) absorption of cyanide compounds through the skin. In addition to the serious health hazards, federal regulations are making it more difficult to dispose of all cyanide wastes. For example, the Resource Conservation Recovery Act (RCRA) precludes the practice of landfilling leachable or liquid cyanide wastes.

New noncyanide metal stripping formulations and processes are being investigated and used by industry because of increasing concern for worker safety and more stringent regulations governing hazardous waste treatment and disposal. The chemistry of metals exposed to most mineral acids, inorganic bases, ammonia, and water has been known for years. It is from this information that most currently available noncyanide strippers were developed. Many of these are acidic or basic solutions that may or may not contain other additives. Significant advances in metal stripper technology in the last ten years has resulted in the availability of a fair number of commercial noncyanide formulations. These commercial formulations have been developed for some of the specific plate metal/basis metal combinations listed in Table 1. Several of these are currently being used in large-scale industrial electroplating facilities.

The Air Force could benefit highly from these new technologies if they were implemented into ALC electroplating shops. Reduced use of cyanide products will result in reduced contact time for personnel to the associated hazards. This will increase the margin of safety for all personnel who handle cyanide during the course of their work. This will also impact a large number of people along a path from the initial distributors to the final waste treatment personnel. Additionally, the replacement of cyanide strippers with

TABLE 1. COMMERCIAL STRIPPING SOLUTIONS TESTED DURING PHASE III OF NCYS.

| <u>Company Name</u> | <u>Product</u> | <u>Surface Coating</u> | <u>Basis Metals</u> |
|----------------------|--------------------------------------|----------------------------------|--------------------------------------|
| Electrochemicals | Nickel-Sol | Nickel, Copper | Aluminum, Plastics, Stainless steels |
| Enthone, Inc. | Enstrip N-190 | Electroplated nickel | Steel, Copper alloys |
| Frederick Gumm Chem. | Clepo 204 (Immersion) | Nickel | Mild steel |
| McGean-Rohco, Inc. | Rostrip Electrolytic Stripper 999-SP | Copper, Nickel, and other metals | Steel |
| Metalk, Inc. | B-9 Nickel Stripper | Nickel | Steel |
| M&T Harshaw | Ni-Plex 100 Strip | Nickel | Steel |
| Technic Inc. | Non-Cyanide Silver Stripper | Nickel-iron plate | Ferrous metals |
| Technic Inc. | Cy-less Electrolytic Gold Stripper | Silver | Various basis metals |

noncyanide alternatives can reduce the amount of cyanide entering the environment through accidental spills or from inefficient removal during the waste treatment process. The less toxic and more inherently biodegradable noncyanide alternatives impart greater flexibility in restoring the environment if spills or problems in waste treatment occur.

Other relevant background material concerning Air Force applications and the reasoning behind this program can be found in the Final Reports from Phases I, II and III of the NCYS Program (refs. 1-3). Below is a brief summary of the activities and achievements of the NCYS Program.

1. Phase I Activities of the NCYS Program (FY-88)

Phase I activities involved gathering and organizing information on commercially available cyanide and noncyanide strippers, and running laboratory-scale performance tests using metal coupons representative of materials used by the Air Force. A summary of the activities for Phase I is given below.

PHASE I TASKS:

- Investigated and compiled a list of Air Force refurbishing processes that use cyanide solutions and generate cyanide wastes.
- Determined the specific Air Force applications (plate metal/basis metal combinations) exposed to cyanide solutions.
- Evaluated the state-of-the-art in noncyanide metal stripping technology.
- Obtained commercially available noncyanide metal stripping products.
- Performed laboratory performance tests on commercial products (tailored to meet Air Force performance requirements and waste minimization objectives).
- Provided a summary report to indicate the findings (ref. 1).

2. Phase II Activities of the NCYS Program (FY-89)

Phase II activities included a continuation of the laboratory evaluation of commercial immersion and electrolytic strippers that were not available in Phase I. Phase II activities also involved scaled-up field verification tests at an on-site field testing facility for those commercial nickel strippers that showed good performance characteristics in Phase I tests. Investigations into the fundamental mechanisms involved in the stripping processes were initiated in an attempt to evaluate the feasibility of formulating generic noncyanide strippers "in house". In recognition of the fact that a suitable noncyanide precious metal stripping process must allow for precious metal recovery, investigations were conducted to recover silver from several spent silver stripping solutions. A summary of the activities for Phase II is given below.

PHASE II TASKS:

- Constructed a Field Test Facility (FTF) near the Kelly AFB Building 301 Plating Shop.
- Obtained baseline data for cyanide stripping processes used in Building 301 at Kelly AFB.
- Completed laboratory-scale testing of commercial strippers not available for testing in Phase I.
- Completed laboratory-scale evaluation of noncyanide silver stripping processes and commercial formulations.
- Conducted field tests with five commercial noncyanide metal strippers.
- Investigated the fundamental processes that occur during metal stripping for nickel, copper, and silver.
- Initiated laboratory-scale evaluation of commercial silver recovery processes from solutions and sludges to determine their suitability for treating noncyanide silver wastes.
- Summarized the findings in a Phase II Final Report (ref. 2).

3. Phase III Activities of the NCYS Program (FY-90)

Phase III activities included the first attempts to determine the treatability (biodegradability) of the organic constituents of the new noncyanide nickel strippers. Field testing of most commercial noncyanide nickel and silver strippers reached completion. Two nickel strippers were implemented into production usage at the plating shop at Kelly AFB. The tests to formulate generic nickel strippers were continued and yielded at least one formulation which was recommended for field testing the following year. These tasks are summarized below.

PHASE III TASKS:

- Implemented CLEPO 204 (Frederick Gumm Chemical Co., Inc.) and Nickel-Sol (Electrochemicals) into the plating shop at Kelly AFB.
- Conducted field tests on the following commercial nickel strippers: B-9 Nickel Stripper (Metalex, Inc.), Ni-plex 100 (M&T Harshaw), and Enstrip N-190 (Enthone-OMI, Inc.).
- Conducted field tests on commercial silver strippers that showed good performance characteristics during laboratory investigations conducted during Phase II. These included: Rostrip 999-SP Electrolytic Silver Stripper (McGean-Rohco, Inc.), Non-cyanide Silver Stripper - Electrolytic (Technic Inc.), and Cy-Less Electrolytic Gold Strip (Technic Inc.).
- Continued electrochemical testing to formulate a new generic nickel stripper which could be implemented into use at AFB plating shops with particular attention paid toward waste treatment and toxicity characteristics as well as stripping performance.
- Initiated laboratory-scale biodegradation tests to determine if the activated-sludge culture at Kelly AFB could be induced to degrade ethylenediamine.
- Summarized the findings in a Phase III Final Report (ref. 3).

4. Results From Phases I - III of the NCYS Program

a. Laboratory Performance Evaluation Tests

During Phases I and II of the NCYS program, a total of 32 commercially available noncyanide strippers were evaluated using laboratory-scale tests (Appendix B). Stripping solutions that met performance criteria for stripping rates, basis metal protection, and compatibility with existing wastewater treatment facilities were targeted for field testing. A number of the strippers that exhibited acceptable performance in Phases I and II are comprised of solutions high in mineral acid, contain large fractions of highly volatile components, or require electrolytic operating conditions. Although these conditions have been acceptable in the past, as evidenced by the use of similar process solutions in the ALCs, other products are available that perform better for most Air Force applications. Unfortunately, the treatability of these products by existing activated-sludge treatment processes at the Kelly AFB IWTP was in question. This is why we pursued laboratory and pilot-scale biodegradability and compatibility testing of the organic components found in new generation non-cyanide formulations (discussed later in this report).

Three nickel strippers demonstrated stripping rates greater than 1 milliinch per hour for electrolytic nickel (a sulfamate nickel) plated according to Technical Order 42C2-1-7 (ref. 7). These strippers include: Nickel-Sol, Patstrip Ni, and CLEPO 204. These solutions were recommended for field testing since they all had stripping rates greater than the Air Force Cyanide Immersion (C-106) process, which had a measured stripping rate just under 1 milliinch per hour for the electrolytic nickel plates.

The process conditions for these noncyanide strippers fall into either of two major categories: immersion or electrolytic. Immersion stripping occurs spontaneously when the part is immersed in the stripping solution. In contrast, electrolytic stripping requires a voltage to be applied to the parts while immersed in the solution. Many differences exist between these two techniques. The electrolytic process is generally used as a last resort since it has electrical shock hazards associated with it and

requires careful racking and monitoring of the parts while being stripped. It does have the benefit of a faster stripping rate; however, this speed may be uncontrolled and require that a constant vigil be kept by the operator. In the case of silver stripping, electrolytic methods are presently the only way to remove silver from low alloy and high carbon steel parts.

The results from the silver stripping tests showed that none of the commercial formulations could approach the average stripping rate obtained in laboratory tests using the Air Force Electrolytic Cyanide (C-101) process. It is not anticipated that any noncyanide silver stripper will be able to approach the performance of the electrolytic cyanide stripper because no other formulation can duplicate the tenacity of cyanide to function as a complexing agent for silver. However, out of the 19 strippers tested, 10 produced stripping rates greater than 1.0 milliinch per hour. This rate is roughly comparable to the rate (2.38 milliinch per hour) that was obtained when testing the Air Force C-106 process during Phase II of the NCYS Program. Although each of these 10 noncyanide formulations showed good protection of stainless steel, only six of them provided adequate protection of low alloy steel (LAS). The formulations that did not provide adequate protection of LAS tended to be acidic and were assumed to lack additional agents needed for passivation of the metal surface (the process which prevents corrosion). Only three of the commercial products were recommended for field testing. All of these solutions were electrolytic and included: Rostrip 999-SP Electrolytic Silver Stripper (McGean-Rohco, Inc.), Cy-Less Electrolytic Gold Strip (Technic Inc.), and Non-cyanide Silver Stripper - Electrolytic (Technic Inc.).

b. Field Tests of Noncyanide Strippers

During Phase II of the NCYS Program (ref. 2), five commercial noncyanide metal strippers and the Air Force C-106 process were tested. All exhibited a wide range of performance characteristics. Not all of those characteristics were the same as exhibited in the Phase I laboratory tests. The commercial strippers tested were Cirstrip NCN-CU (Circuit Chemistry Corporation), XPS-306 (Enthone-OMI, Inc.), Nickel-Sol Process (Electrochemicals), Patstrip Ni (Patclin Chemical Company), and CLEPO 204 (Frederick Gumm Chemical Company).

The three nickel strippers that were field tested during Phase III did not have prior laboratory testing performed by EG&G Idaho, Inc. These strippers were recommended for field testing by personnel at the Kelly AFB plating shop. The laboratory tests for two of the strippers had previously been performed by personnel at the plating shop for: Ni-plex 100 (M&T Harshaw) and Enstrip N-190 (Enthone-OMI, Inc.).

Of the strippers which underwent field testing, the ones that were recommended for implementation into the plating shop at Kelly AFB included: B-9 Nickel Stripper (Metalex, Inc.), Ni-plex 100 (M&T Harshaw), Nickel-Sol Process (Electrochemicals), and CLEPO 204 (Frederick Gumm Chemical Company). The strippers that were not recommended included: Cirstrip NCN-CU (Circuit Chemistry Corporation), XPS-306 (Enthone-OMI, Inc.), Patstrip Ni (Patclen Chemical Company), and Enstrip N-190 (Enthone-OMI, Inc.). The first two rejected strippers (NCN-CU and XPS-306) are ammonia-based with annoying fumes and extensive maintenance requirements. The Patstrip Ni was too corrosive toward the basis metals, while the N-190 was not recommended since it is similar in composition to, and slightly less effective than, CLEPO 204.

Of the three silver strippers that were field tested, only the Rostrip 999-SP exhibited a high silver stripping rate (about 8 milliinch per hour) and was recommended for implementation. This recommendation was made with the stipulation that Haynes and Inconel basis metals not be used since both were attacked. It may be worth noting that these two high alloy steels were attacked by all three of the noncyanide silver strippers that were tested.

c. Implementation Tests of Noncyanide Strippers

As a stripper successfully passed the field test stage, it was implemented. This was done so that the cyanide strippers could be removed from the plating shop as quickly as possible rather than waiting until all solutions had completed field testing. Both CLEPO 204 and Nickel-Sol were implemented into the plating shop during Phase III of the NCYS Program.

CLEPO 204 was implemented to strip electrolytic nickel plates from ferrous substrates. Since implementing this stripper, we have received only positive feedback from the plating shop personnel. They have regarded this stripper so highly that it is still in use. Unfortunately, the Nickel-Sol Process did not fare as well. Due to the daily analysis required to maintain this stripper, the plating shop at Kelly AFB has discontinued its use. This was done in spite of the fact that it may be the most effective stripper for the removal of high phosphorus nickel coatings from stainless steels.

d. Electrochemical Evaluation of Stripper Components

We have discovered that several corrosion measurement techniques can be applied to the task of formulating new generic nickel strippers. The following electrochemical techniques were used: zero-current potential measurements, anodic potentiodynamic polarization, and Tafel analysis. They have been used to determine the corrosion (and stripping) behavior of several plate and basis metals when immersed in aqueous solutions of potentially active stripping chemicals. These chemicals, tested individually or mixed as a formulation, included various types of chemical oxidants, complexing agents, and corrosion inhibitors.

Through a series of these tests, one particular nickel stripping formulation was developed during Phase III of the NCYS program. It is composed of: ethylenediamine, concentrated nitric acid, sodium nitrate, sodium *m*-nitrobenzenesulfonate, and ammonium thiocyanate. This generic nickel stripper was further refined and field tested this year (see Results section below). The use of electrochemical techniques have proven indispensable for quickly screening a large number of potential nickel stripping formulations in a relatively short amount of time.

e. Biological Waste Treatment of Noncyanide Stripper Wastes

Preliminary laboratory tests conducted during Phase III showed that ethylenediamine, a primary organic component of new generation noncyanide metal stripping formulations, was degraded in shake-flask tests using activated-sludge from the Kelly AFB IWTP. Once biodegradability had been

confirmed, ethylenediamine was then scheduled to undergo further laboratory-scale testing to determine compatibility with the Kelly AFB IWTP. This report details those findings.

f. Precious Metal Recovery

Tests conducted during Phase II of the NCYS Program utilized selected spent solutions and sludges obtained from silver stripping tests to determine the feasibility of silver recovery processes. Techniques used to recover silver from solid precipitates (or sludges) included: 1) dissolution of the solid using a solution of a strong chelating agent followed by electrowinning of the metal, and 2) reduction of the sludge with a fused-salt flux. Techniques used to recover dissolved silver from spent stripping solutions included: 1) precipitation of silver chloride from the solution, 2) reduction with sodium borohydride, and 3) electrowinning after adjusting the pH of the solution.

Average recoveries, calculated in terms of elemental silver, ranged from about 87 to over 99 percent depending on the technique used. The lowest recoveries were achieved for the pH adjustment/electrowinning technique, while the highest percentage recoveries were achieved with borohydride reduction. The low performance exhibited by the electrowinning process may indicate a need for further optimization studies. The flux recovery process was only feasible with large sample volumes which allowed the molten silver to agglomerate. The silver recovery testing was not pursued beyond Phase II when our host base expressed a lack of interest in pursuing this technology.

g. Fluid Agitation

Metal finishing process solutions require agitation to fully benefit from the chemical action attainable in process tanks. Agitation, or mixing, of the solutions: 1) ensures uniform distribution of chemicals in the tanks, 2) enhances mass transport of active ingredients to the part surface, 3) increases the deposition rate of materials during plating processes, 4) enhances mass transport of undesirable reaction products away from the part

surface in stripping and metal activation operations, 5) enhances mass transport of various soils away from the part surface in cleaning operations, 6) facilitates rapid temperature equilibration in process tanks, and 7) ensures uniform temperature distribution throughout the tanks.

Three different manifold configurations were tested during Phase III. The results of these tests determined that a one-legged manifold system appeared to offer the best agitation characteristics when compared with a two- or three-legged system. Further research would have to be performed before specific recommendations for implementation could be made. Fluid agitation was not investigated after Phase III due to a lack of funds.

C. SCOPE

With the end of the majority of the research and development related tasks of the NCYS Program has come the start of the demonstration stage with its emphasis centered on technology transfer and installation activities. The information obtained during the previous NCYS Program has been used to determine how the scope of work for the DNCYS Program will be fashioned. The expanded scope of work incorporates a continuation of previous tasks, with additional tasks being performed, which are associated with the use of alternative metal stripping formulations and the treatment of their wastes.

1. Phase I Activities of the DNCYS Program (FY-91)

The only metal stripping field tests conducted this year at Kelly AFB were for a generic nickel stripper formulation. Based upon last year's field test results, Metalx B-9 and Rostrip 999-SP were implemented at Kelly AFB with the support and cooperation of the plating shop manager and personnel.

Biodegradability and compatibility testing of noncyanide metal stripping wastes continued. Stage I (shake-flask) and stage II (continuous-flow bioreactor) tests were conducted using ethylenediamine and spent CLEPO 204 as substrates.

The tasks conducted during Phase I of the DNCYS program are summarized below.

PHASE I TASKS:

1. Noncyanide Stripper Implementation
 - a. Implemented Rostrip 999-SP Electrolytic Silver Stripper (McGean-Rohco, Inc.) into the plating shop at Kelly AFB.
 - b. Implemented B-9 Nickel Stripper (Metalx, Inc.) into the plating shop at Kelly AFB.
 - c. Generated the appropriate documentation for introduction and use of these strippers into other ALC plating shops.
2. Generic Nickel Stripper Development and Testing
 - a. Completed field testing of a generic electrolytic nickel stripper which also strips electroless nickel.
 - b. Used electrochemical techniques to develop an electroless nickel stripper.
 - c. Tested electroless nickel strippers using laboratory-scale reactors.
3. Biological Treatment of Noncyanide Metal Stripper Wastes
 - a. Stage I shake-flask tests were conducted using spent CLEPO 204 as the substrate. The primary constituents were 33 percent ethylenediamine, 10 percent sodium *m*-nitrobenzoate, and an unidentified "red" colored component.
 - b. Stage II continuous-flow bench-scale bioreactor tests were conducted using ethylenediamine and spent CLEPO 204 as substrates. Both tests were conducted at pH 7.0 and 8.5.
4. Reports
 - a. Provided progress reports for Air Force review of current status.
 - b. Provided a final report, in Air Force format, including data, conclusions, and recommendations derived from the test results.

SECTION II

RATIONALE AND METHODOLOGY

A. PROGRAM APPROACH

The DNCYS Program and its predecessor, the NCYS Program, pursue a comprehensive programmatic approach. Initially, the NCYS program started with the evaluation of the state of technology of commercial noncyanide metal stripping products. This was followed by identification and testing of a number of commercial metal strippers. While the commercial strippers underwent testing, generic metal stripping formulations were being developed. Other technologies, such as waste treatment, metals recovery, and fluid agitation were simultaneously being developed.

This approach is comprehensive in that it recognizes that the noncyanide metal stripping technology in itself is not a singular, all inclusive technology which can achieve the underlying goal of waste minimization. Rather, it is one of many waste minimization technologies which must be compatible with, and supported by, other waste minimization technologies within the ALC complex. In this regard, the stimulus behind investigations into the support technologies was to allow the Air Force to realize the full benefit of both increased waste minimization and increased performance of noncyanide metal strippers.

A broader scope of work has been pursued than the program title would suggest. This scope has included silver recovery, fluid agitation, red colored water identification and eradication, cyanide cleaning solution replacement, and waste treatment. The intent has always been to discover what problems were confronting the personnel in the plating shop, and at the IWTP, and help wherever possible. This has lead to expansion into areas of process enhancement not known or identified when the program was first initiated. This includes investigative work into biodegradation and the "red water" problem. Unfortunately, both the Kelly AFB IWTP and the plating shop at Kelly AFB are dynamic entities with different and constantly changing needs and

processes. This fact requires a vast array of technical expertise be made available as a resource to resolve problems ranging across many different disciplines. In light of this, it can be seen why this program has expanded to cover a broader scope and has required additional time to reach completion.

Within the past four years, the needs of the plating shop have changed dramatically. The need for an electroless nickel stripper with the ability to remove high phosphorus nickel plates may become increasingly important. This contrasts with the past effort which has been directed at finding electroless nickel strippers which would remove the plates currently used by the Air Force. These correspond to a middle to low phosphorus containing electroless nickel plate (generally less than 7 percent phosphorus). While a high phosphorus coating may be removed using acidic solutions (Nickel-Sol) and/or electrolytic strippers (Rostrip 999-SP), its present use has lead to plate materials which cannot be adequately stripped using alkaline immersion processes, especially after heat treatment.

B. COMMERCIAL NONCYANIDE METAL STRIPPING PRODUCT TESTING

The procedure used to determine whether commercial products would meet the needs of the Air Force went through the following sequence of steps. The new products were first analyzed for contents and those with extremely toxic or objectionable components were discarded. At the Air Force's request, those strippers containing phenol were eliminated. After passing this first stage, each stripper was then prepared according to the manufacturer's directions and tested using solution volumes of 250 mL. This laboratory scale testing has been identified as "jar" tests. At this point, only the best strippers were singled out for further testing using the larger volumes of 38, 57, 76, or even 380 liters (10, 15, 20, 100 gallons). This has been identified as the "field" test stage and was meant to bridge the gap between results obtained using laboratory (jar) test solution volumes, with those that would be obtained using stripping tanks in the plating shop. The field test stage was also used to optimize the operating parameters of the stripping formulation. Once a stripper has passed this sequence of tests, it would then be cleared for implementation into the plating shop.

This sequence of tests was meant to "weed out" those strippers which would not work. This would save the Air Force and its plating shops the expense of purchase and disposal of the strippers used for testing. This expense could be significant if one were to consider the number of strippers tested and the volumes required. The "weeding out" tests also helped to avoid production delays which could have arisen from the dedication of a number of different tanks to the testing of these strippers. This sequential approach to testing provided a smooth transition from performing a large number of small volume tests, to only a few full-scale implementations of the superior products into the plating shops at Air Force facilities.

Other criteria used to select stripping solutions to be tested included: biodegradability, pH of the solution, and electrolytic versus immersion processes. A successful candidate solution must first be biodegradable, then compatible with existing waste treatment facilities. A large number of ethylenediamine based solutions were tested since the scientific literature indicated that ethylenediamine was inherently biodegradable. However, ethylenediamine is not presently treated at the Kelly AFB IWTP. The biodegradation testing was pursued to determine if these solutions could be biodegraded by the activated-sludge culture at Kelly AFB. Another reason for helping make the ethylenediamine based strippers useful is because they are favored over the acidic strippers; since acids can only be used with stainless steel parts. Finally, immersion strippers are also highly preferred to any electrolytic stripping solutions; since electrolytic conditions are inherently aggressive to all metals, and require constant monitoring during use.

1. Generic Noncyanide Metal Stripper Development

The Air Force has a commitment to remove cyanide stripping processes from their operations. There are two primary technical reasons for the widespread use of cyanide in stripping solutions. First, cyanide has the ability to change the electrochemical behavior of most metals, allowing them to be oxidized more easily and thus, more easily stripped. Second, cyanide is a strong complexation agent that readily binds to the oxidized surface species and facilitates dissolution. The stripping reaction is initiated by oxidation of the surface metal atoms, usually from the zero-valent (metallic) state to a

higher (ionic) one. When the oxidized surface species is dissolved by transport into the bulk solution, a fresh metallic surface becomes exposed and is subsequently oxidized. Thus, a cycle is established wherein a clean metallic surface is repeatedly oxidized and dissolved. In developing noncyanide strippers, the chemical and electrochemical properties of the constituents affecting dissolution and solvation of the oxidized metal species must be carefully considered.

Prior laboratory investigations performed in Phase II of the NCYS Program examined the fundamental mechanisms involved in the stripping process. The purpose of these investigations was to determine the behavior of metal surface atoms and ions in the presence of potentially useful alternative solvents, chelating agents, and known surface passivation agents. The chemicals selected for study included those deemed suitable for future commercialization as alternative stripping reagents. Laboratory formulations of these reagents are called "generic" strippers in this report. Such solutions were to be comprised of inexpensive compounds that strip successfully, are relatively non-toxic, and are easy to biodegrade.

Some of these compounds have already been studied by the electroplating and mining industries with good results and are available as proprietary formulations from their respective companies. However, the Air Force has some specific stripping applications, such as removal of silver, that have not received much attention in the commercial sector. Therefore, significant development work in this area remains unexplored. A noncyanide silver stripper is needed that will simultaneously strip silver at an adequate rate and produce a low-hazard sludge that is readily recoverable. The current cyanide silver strippers produce sludges that are classified hazardous wastes (ref. 5), and must be closely monitored prior to and during transportation to commercial agencies for recovery.

Test results from Phase II of the NCYS Program demonstrated that electrochemical methods could be used to successfully develop a generic stripper. The advantages of this method of study are twofold. First, formulations specific to Air Force applications can be developed. Secondly, the cost of using these formulations will be low since the ingredients will be

known and can be purchased in technical-grade, bulk quantities. It was discovered that the following classes of components are needed to create a successful stripper formulation: 1) an oxidizing agent to oxidize the surface plate metal and render it in a soluble form, 2) a complexation agent to physically transport the oxidized plate metal from the surface into the bulk solution, 3) pH adjusting agents to aid the oxidation and solubilization steps, and 4) corrosion inhibitors to prevent attack of the solution upon the basis metal.

The development of stripping formulations can become quite complex. The oxidizing agents are aggressive toward most metals and in some cases more aggressive toward the part than the plated coating. In addition, the chelating agents affect the oxidation properties of the plate and basis metals to different degrees. In most stripping formulations, the oxidizing agents and chelating agents are matched to impart a greater effect on the plate metal than on the basis metal; however, the basis metal is still typically susceptible to attack. This is why a corrosion inhibitor is routinely included in the stripping formulation.

The corrosion inhibitor can function in several different ways to provide protection to the part. It may provide competing pathways to slow attack at the solution/part interface (in which case, dissolution of the plate metal is also hindered). It may render the basis metal surface inactive to the solution components (this is desirable if the protection is not due to the formation of a barrier layer resulting from initial degradation of the part). It may also provide a protective coating on the basis metal surface through chemisorption. This latter condition is the most desirable from a theoretical perspective since the plate metal stripping rate should not be appreciably affected. This is also the most difficult situation to achieve because of the required specificity.

Water soluble nitroaromatic compounds demonstrate effective corrosion inhibition properties on most ferrous alloy surfaces and are a major component of Air Force cyanide stripping solutions. They are inexpensive, relatively nonhazardous, stable, and convenient to use in many applications. Unfortunately, there are many competitive side-reactions in which they can

participate (e.g., complexation to metals, substitution reactions, and degradation), with essentially no change in contribution to the Chemical Oxygen Demand (COD). In addition, the stripping process generates an intensely colored species which is not readily degraded with existing chemical or biological waste treatment processes. This coloration has even been observed to intensify during the alkaline chlorination process used to degrade cyanide. This colored species poses a problem since it is not readily degraded in the waste treatment facility and yields a wastewater which meets organic concentration discharge limits but is too highly colored for release. This "Red Water" problem will not be solved by simply replacing the cyanide stripping solutions with alternates since most commercial formulations also contain these nitroaromatic inhibitors as key ingredients. This is why the red water research was initiated and is discussed in its own section below.

In Phase III of the NCYS Program, literature was used to aid in the identification of formulations and active ingredients which have been shown to strip the desired plate metal while protecting the basis metal (refs. 8-30). Electrochemical techniques were then used to screen a large number of chemicals in a short period of time for their attack upon plate and basis metals. The following list of electrochemical techniques were used because they are fast and produce substantially lower volumes of waste than standard jar testing (refs. 31,32):

- Potentiodynamic Anodic Polarization provides a relatively rapid means for approximating the corrosion potential (E_{corr} or E_{oc}) and the theoretical corrosion rate.
- Tafel Plots provide a better approximation of the corrosion potential (E_{corr}) and the theoretical corrosion rate, but they can take longer to perform.
- Zero-Current Potential measurements provide the most accurate means of determining the corrosion potential (E_{corr}), unfortunately, the time needed for this technique may be excruciatingly long since it requires waiting for the electrode to reach equilibrium with the solution.

After the screening of the most effective stripper components was complete, mixtures of these chemical agents (formulations) were tested using the same electrochemical methods. An attempt was made to maximize the efficiency of these formulations before starting the laboratory phase of testing.

2. Laboratory Testing of Commercial Noncyanide Metal Stripper Formulations

The overall objective for Phase I of the NCYS Program (ref. 1) was to evaluate the commercial noncyanide formulations and processes using a small laboratory-scale set of experiments. This preliminary screening process was used for selecting the best products to scale-up for future field testing. In the past, metal strippers were considered for selection based upon their stripping process performance. Stripping performance characteristics are:

- Effectiveness of the process
- Time required to remove the coating
- Cost of the operation
- Reliability of the process

Although these criteria are important, they are no longer the only considerations in the choice of strippers. The list has been expanded to include:

- Method of waste treatment
- Health hazards to personnel
- Product safety
- Materials recovery
- Energy conservation
- Public opinion

Some of the last six criteria have, in fact, been given higher priority in selecting a stripper than the first four. The reprioritization is in response to stringent waste disposal laws enacted, or forecast for enactment; to the

passage of the Resources Conservation and Recovery Act (RCRA); and the Occupational Safety Hazards Act.

To achieve the overall objective of Phase I of the NCYS Program, noncyanide strippers were evaluated for potential application and incorporation into the electroplating shop at Kelly AFB. Strippers were evaluated in five areas of performance: 1) plate metal stripping efficiency, 2) basis metal protection, 3) masking material compatibility, 4) operating conditions, and 5) biodegradability of the solutions containing organic compounds. These performance characteristics were experimentally evaluated in the laboratory under conditions representative of operations at Kelly AFB. Acceptable stripper performance in these areas provided the technical foundation to warrant field verification studies in preparation for implementation of these new technologies.

The plate metal stripping and basis metal corrosion rates were determined using ASTM Designation: G 1-81 a Standard Practice for PREPARING, CLEANING, AND EVALUATING CORROSION TEST SPECIMENS (ref. 31). This procedure outlines how the tests for stripping/corrosion rates are performed without stipulating any requirements for the solutions being tested.

The standard test procedure discusses the cleaning and corrosion testing of metal coupons. These coupons are measured as accurately as possible (generally 3 to 4 significant figures) using an analytical balance and calipers. The equation used to calculate the stripping rate is as follows:

$$SR = Xm(1/D)(1/SA)(1/t)(1000 \text{ mil}/2.54 \text{ cm})$$

where SR is the stripping rate (in millinch per hour), Xm is the mass change (in grams) for the coupon, D is the density of the coupon material (in grams per cubic centimeter), SA is the surface area of the coupon (in square centimeters), and t is the time (in hours) for which the coupon was exposed to the stripping solution. The surface area of the coupons was calculated from the physical dimensions of new coupons or on the measured dimensions for masked coupons. For example: a coupon has the dimensions, 1 by 2 by 1/8 inch

with a 1/4 inch hole bored through it. The surface area (SA, in square centimeters) is calculated using the following equation:

$$SA = (2hw + 2ht + 2wt - 2\pi r^2 + 2\pi rt)(2.54 \text{ cm/in})^2$$

or $2(FA + TE + SE + 1/2HE - HFA)(2.54 \text{ cm/in})^2$

where h is height, w is width, t is thickness, and r is radius of the hole in the coupon (all in inches); from the above example, FA is the face area (2 square inch), TE is the top edge area (1/8 square inch), SE is the side edge area (1/4 square inch), HE is the exposed edge of the bored hole (0.098 square inch), and HFA is the area missing from the coupon face due to the bored hole (0.049 square inch).

It may appear at first glance that there is a redundant conversion used in the calculation of the stripping rate. In the equation for the stripping rate, there is a conversion for changing centimeters to inches while in the calculation for the surface area, the reverse appears - conversion of inches to centimeters. While this may appear redundant, it is not. The problem lies in the units for the density which are grams per cubic centimeter. The weight loss is in grams and this matches those of the density; therefore, the units for the surface area must also be in centimeters in order to match. The final conversion is performed to provide a stripping rate that is more meaningful to plating shop personnel who are still more familiar with the American system of measurements (milliinch per hour).

Error analysis of the equation shows that the stripping rates with the largest errors are those that have insignificant mass changes that cannot be detected within the accuracy of the instruments and those with mass changes so large that the dimensions of the coupon are significantly changed. In either case, the results are still meaningful since they indicate extremely low corrosion rates (i.e., excellent protection), or extremely fast stripping rates, respectively. The quality of corrosion test results can be improved by increasing the reaction time (generally 24 hours - anything longer would represent unrealistic test conditions for an AFB plating shop). The high stripping rate measurements can be similarly improved by decreasing the reaction times to the point where significant mass changes still occur, but

are not so large that the dimensions become grossly affected. This is why 1 hour tests for the electrolytic nickel plates and 2 hours for the electroless nickel plates were chosen.

Another source of error arises when the stripping reaction leaves a scale or smut on the surface of the coupon. For basis metals, the presence of scale or smut indicates that the surface has been corroded and should be scrubbed off. The total weight loss was used for the calculation of the corrosion rate. In order to avoid confusion and keep the procedure consistent, both basis and plate metal coupons were scrubbed before making weight loss measurements.

The density of the materials used in the calculations can introduce significant error in the results if the density of the particular specimen is different from the literature value, or more importantly, different from the other test coupons. This is why an attempt was made to make all tests as consistent as possible by using coupons from the same lot number. It is also important to note that since a density was not available for the nickel plated coupons, the density for pure nickel (8.90 g/cm^3) was used for all coupons. While this may not yield an accurate value for the stripping rate, the introduction of a consistent error in all tests still allows for comparison of stripping rates from one test to another.

Reaction time can be measured to the nearest second and introduces an insignificant amount of error.

3. Field Testing of Noncyanide Metal Strippers

Noncyanide strippers which performed well in laboratory tests were selected for field testing as a prerequisite to incorporation into the existing metal finishing shop at Kelly AFB. The same procedure that was used to determine plate metal stripping rate and basis metal protection for the laboratory investigations was used in the field tests. Basis metal protection was determined by visual and microscopic inspection for corrosion, pitting, etching, and staining in addition to weight loss calculations. The resulting stripping and corrosion rates, along with visual inspection data, were used to

determine whether a noncyanide stripper would be recommended for implementation. The field tests were meant to serve as an optimization step, with solution volumes more closely approximating those used in the Air Force plating shop. Field testing of commercial strippers was completed during Phases II and III of the NCYS Program. This year, only the generic nickel stripper was tested. The stripper was prepared as recommended by the developer.

Stripping performance was determined for the following plate or surface coatings: electrolytic and electroless nickel, nickel-boron, and silver. The effect these stripping solutions have on basis metals (including corrosion and pitting) was determined for low alloy steels (C4340 and D6AC), stainless steels (17-4PH, 316, and 410), a nickel alloy (Inconel 718), and a cobalt alloy (Haynes 188). The materials were tested within the acceptable range of conditions used in the electroplating shop. Temperatures ranged from ambient to 65°C (150°F). Processes that work acceptably at lower temperatures were emphasized because of the increased worker safety. Additionally, air or mechanical agitation and conventional cross-flow ventilation systems (representative of Air Force facilities), were used to determine if existing ventilation and agitation systems will be compatible with the new stripping solutions. These systems were also used in order to provide data that would be consistent with the plating shop. This would yield results that would be similar to those expected in the plating shop and uncover any major incompatibilities before the product reaches the production environment.

The optimization process looked at the following solution parameters: pH, temperature, longevity, nickel loading, and regeneration. The tanks were operated with mechanical agitation. These parameters were tested to determine the optimal conditions for stripping the specified plate metal(s), while simultaneously affording protection to the desired basis metals.

4. Implementation of Noncyanide Metal Strippers

At the request of the Air Force, implementation was performed as soon as a stripping formulation successfully completed field testing, rather than waiting for the completion of field testing on the entire set of strippers.

This was done to rid cyanide from the plating shop as soon as possible since the products were already of proven capability from both laboratory and field tests. Our role in the implementation process was to monitor the stripping and corrosion rates of the solutions and to supply guidance in maintenance operations. The plating shop at Kelly AFB dedicated the stripping tank and supplied the aircraft parts used in the evaluation. They also provided labor for solution preparation, maintenance, regeneration, and analysis.

C. BIOLOGICAL TREATMENT OF NONCYANIDE METAL STRIPPING WASTES

The IWTP at Kelly AFB is comprised of the paint stripping waste pretreatment facility, the electroplating waste pretreatment facility, the batch treatment facility, and the central treatment facility. The paint stripping waste pretreatment facility receives concentrated and dilute industrial wastewater from buildings 365, 375, and 385. This wastewater undergoes chromium reduction, precipitation of heavy metals, and biological treatment (72 hour contact time at an average flow rate of 30 gallons per minute). The treated wastewater from the paint stripping waste pretreatment facility was initially designed to be discharged to the City of San Antonio; however, the wastewater is currently being added to the "raw" waste stream which is identified as the waste stream that feeds the central IWTP equalization basins.

The electroplating waste pretreatment facility receives moderately concentrated (rinse water) industrial wastewater from buildings 301 and 360. Cyanide in this wastewater has been treated prior to this waste reaching the IWTP. The electroplating waste pretreatment facility provides treatment for chromium reduction, metals precipitation, and pressure filtration. The treated wastewater from this pretreatment facility was initially designed to be discharged to the City of San Antonio; however, the wastewater is currently being added to the "raw" waste stream where it is diluted 1:40.

The batch treatment facility is a large tank which is used for treatment of concentrated wastes received from metals refurbishing shops on base. Usually, this treatment facility is used for the precipitation of heavy

metals. Treated wastes from this facility are added to the equalization basins which contain other industrial wastes of a similar nature.

The central treatment facility receives all wastewater from the "raw" waste stream. When the IWTP was initially designed, the "raw" waste stream contained only a few diluted organics derived from sources other than the industrial processes on base. Thus, the central treatment facility was initially designed to process the relatively dilute wastewaters generated base-wide (e.g., rain water from storm drains). The "raw" wastewater which enters the central treatment facility is subject to flow equalization, biological treatment, metals precipitation, tertiary filtration, then post aeration prior to being discharged into Leon Creek. The biological treatment process of the central treatment facility was initially meant to be a "polishing" process designed for treatment of large volumes of relatively diluted wastewaters generated base-wide. While the biological treatment process of the paint stripping pretreatment facility was specifically designed to treat industrial organic chemicals, the central facility biological treatment process was not initially designed to handle a variety of untreated industrial organics. The central facility biological treatment process is now used to treat a "raw" waste stream that a) contains a variety of industrial organic chemicals, b) has an average daily flow rate of 1.3 MGD (million gallons per day), c) receives an average biological treatment time of 4.5 hours.

The waste stream is a constantly changing matrix. Wastes from the metals processing and paint stripping facilities, at the time the IWTP was designed, contained phenolic-based paint stripping solutions and pre-treated cyanide metal stripping solutions, both of which contained heavy metals. The cyanide metal stripping solutions previously used contained up to 10 percent weight to volume of sodium *m*-nitrobenzenesulfonate. Minute concentrations of other organics could also be found. These organics are brighteners and other similar organics; however, the major constituent of cyanide strippers was cyanide. Currently, the IWTP receives both dilute and concentrated wastes from these facilities, and some storm sewers, but the waste stream is significantly different from just a few years ago. Contrary to the intent of the initial treatment design the number of different organic compounds found

in the influent waste streams has drastically increased. Concentrations of these compounds can vary from less than 1 ppm to greater than 2000 ppm. With the implementation of new metal stripping formulations and paint stripping formulations (both of which are comprised mostly of organics), this number is expected to increase further along with the carbon content of the influent waste streams.

The change in the waste stream is mainly due to the fact that many of the current refurbishing processes occurring in buildings 301, 360, 365, 375, and 385 either have already changed, or will change in the near future as a result of waste minimization efforts (such as process changes or chemical substitutions). The current and future IWTP influent already contains, or will contain, more organic acids, terpenes, amines (ethylenediamine, and ethanolamine), aromatic nitro compounds (sodium *m*-nitrobenzoic acid), substituted thiourea compounds (diethylthiourea), caustics, mineral acids, ammonia, nitrates, and sodium bicarbonate; with less phenolic and halogenated organics. The bulk of the cyanide solutions have already been eliminated.

The changes occurring in upstream processes, while intended for waste minimization, bode ill for the IWTP. The IWTP design allows for very little flexibility in treatment methodology and processing parameters such as fluid retention times. Pushed to the limit as it is now, an upgrade of the current IWTP design and a change in waste disposal methodology and treatment, could be required to adequately treat the different chemicals which have found their way into the waste stream. It should be noted that all good intentions for waste minimization in upstream facilities can be defeated if proper waste treatment at the IWTP cannot be achieved ...one problem is eliminated by creating another.

The goal of the waste treatment support technology is to determine if the existing, on-site waste treatment facilities are capable of processing both concentrated and dilute noncyanide metal stripping wastes. Successful treatment of these wastes is defined as a) greater than 99% removal of the targeted organic components, b) the IWTP effluent water quality meets the Kelly AFB IWTP National Pollution Discharge Elimination System (NPDES) requirements, c) introduction of the noncyanide metal stripping components

does not interfere with the biodegradation of other waste stream components, and d) biodegradation of the noncyanide metal stripping components does not give rise to toxic by-products.

1. Stage I Laboratory Experiments

The methodology used to achieve this goal follows a "simplest to most complex" and a "smallest-scale to largest-scale" scheme. This rationale attempts to minimize cost and effort without sacrificing data quality and validity. This rationale also allows a logical sequence of activities and experiments to be followed which assess first the biodegradability potential of targeted noncyanide metal stripper components, then the compatibility of these components with the existing waste treatment processes. Therefore, the first experiments conducted were the "smallest-scale" and "least complex", but provided the most important answer of biodegradability potential. The logic follows that if an organic compound to be tested for biodegradability fails the simplest test, there is very little justification to pursue larger-scale or more complex experiments. If a chemical fails the simplest test, then it should be determined why it failed the test before assuming that it is not biodegradable. It is possible that the experimental conditions (size, complexity, physical and chemical parameters, etc.) were not favorable towards biodegradation. Thus, a false negative result was obtained. It also follows that if an organic compound passes the "simplest" test, then the process of biodegradation should be continually scaled-up and tested under increasingly larger-scale and more complex conditions (conditions which draw closer to actual on-line conditions). This rationale is followed because it is known that many chemicals are inherently biodegradable, but biodegradability may or may not be achieved at the Kelly AFB IWTP because of the uniqueness of its waste stream matrix and treatment process design (i.e., aerobic, completely-mixed activated-sludge system, hydraulic retention times, metals precipitation process, mean cell retention times, etc.).

The method used to perform the "simplest" of laboratory tests was shake-flask experiments using a mixed culture inoculum from Kelly AFB IWTP, a basal salts minimal medium, a moderately low carbon substrate concentration, a spectrophotometric method to determine the increase in cell mass, a gas

chromatograph to monitor the concentration of the substrate over time, and control tests to provide baseline data. This experimental design provides data which incorporates all of the essential requirements needed to justify proceeding to the second level of experiments.

Keeping the "simplest to most complex" idea in mind, the stage I experiments were first conducted using a mono-component (ethylenediamine) substrate. The next logical step beyond using a mono-component substrate was multi-component substrates (ethylenediamine and *m*-nitrobenzoate). The results of the mono-component shake-flask experiments are detailed in the NCYS Program Phase III Final Report (ref. 3). This report outlines similar tests which were conducted on spent CLEPO 204 solutions (ethylenediamine and *m*-nitrobenzoate).

One may wonder why mono-component shake-flask experiments were not conducted using *m*-nitrobenzoate. During shake-flask experimentation it was noticed that the compound being tested (*m*-nitrobenzenesulfonate) did not have the same chromatographic characteristics as the actual nitroaromatic compound in spent CLEPO 204 solutions. The manufacturer (Frederick-Gumm Chemical Co.) was called and asked to disclose the identity of the nitroaromatic component. The response was that the information was proprietary. After further probing and investigation (talks with their lawyer) the manufacturer conceded that the nitroaromatic component was *m*-nitrobenzoate and not *m*-nitrobenzenesulfonate as initially thought. Therefore, the tests being conducted were on the wrong compound. When a *m*-nitrobenzoate standard was obtained, the nitroaromatic component in CLEPO 204 solutions was again not demonstrating the same chromatographic characteristics. After contacting the manufacturer and again informing them that the nitroaromatic component was not *m*-nitrobenzoate as indicated, it was divulged that depending upon current market prices the nitroaromatic used in CLEPO 204 could either be *p*-nitrobenzoate, or *m*-nitrobenzoate. When a *p*-nitrobenzoate standard was obtained, the chromatographic characteristics matched exactly with the nitroaromatic in the current batch of CLEPO 204. The mono-component test was skipped because the results of the multi-component tests, simultaneously being conducted, indicated that biodegradation of the spent CLEPO 204 components had occurred (albeit somewhat poorly). In this report, the nitroaromatic component of

CLEPO 204 is referred to as *m*-nitrobenzoate; although depending upon the batch, the nitroaromatic could be the meta or para substituted species.

2. Stage II Laboratory Experiments

Keep in mind that the goal is to eventually scale-up to the complexity and size of the Kelly AFB IWTP. Therefore, the next step up from the "simplest, least complex" experimental conditions was one of complexity and size. The second stage of experiments was designed to answer the question of compatibility of the targeted substrate with existing treatment conditions at the IWTP.

Because the majority of new generation non-cyanide metal stripper formulations contain ethylenediamine as an active ingredient, ethylenediamine was chosen as a substrate for mono-component bioreactor studies. The commercial formulation CLEPO 204 was chosen for multi-component substrate experiments because CLEPO 204 contains ethylenediamine (33 percent by volume), *m*-nitrobenzoate (10 percent weight to volume), and 1,3-diethylthiourea (0.5 percent weight to volume). The reasons for testing CLEPO 204 were two-fold: it has already been implemented into the plating shops; therefore, constituting a current disposal and treatment problem for Kelly AFB; and because it is representative of other stripping formulations being considered for implementation. The mono-component experiments using *m*-nitrobenzoate as the substrate were also skipped. The reasoning for this was that if the pH 7.0 and pH 8.5 tests were to be run, then a total of eight bioreactors would be in operation. It was physically impossible to run eight bioreactors simultaneously due to space, time, and manpower limitations. Therefore, the multi-component CLEPO 204 experiment was chosen and six bioreactors were run. The method used to perform the Stage II laboratory experiments was the bench-scale continuous-flow bioreactor model.

Bench-scale continuous-flow bioreactor experiments show the effects of introduction and subsequent biodegradation of any organic chemical in the presence of the existing waste stream chemical matrix. These tests also provide data needed to determine the physiological effects a chemical has upon biological activity. This test helps to determine the acclimation time

response, the population distribution of microorganisms in the activated-sludge, the carbon removal efficiency, the substrate concentration tolerance, the possibility of mutually exclusive degradation pathways, and the overall performance and compatibility of biological treatment of the targeted substrate in the existing waste stream. The results from these tests also provide evidence for the feasibility of the technology on a laboratory-scale, and can justify the scale-up of the process to pilot level testing.

Bench-scale continuous-flow bioreactor experiments use IWTP activated-sludge and process water with increasing amounts of the test substrate added over time. These experiments were conducted in the biological field laboratory facility at Kelly AFB where fresh activated-sludge cultures and the current IWTP process water chemical matrix could be easily obtained. An attempt was made to establish an activated-sludge system which would remove 99 percent or more of the influent substrate and not exceed effluent Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD) NPDES quality requirements set for the IWTP. The experiments were also conducted at pH 7.0 and pH 8.5 to cover the pH window experienced at the IWTP.

The continuous-flow bioreactor system utilizes a physical design similar to the aeration basin and clarifier system used at the Kelly AFB IWTP. Air is sparged from the bottom of a polyvinyl chloride column which contains activated-sludge and IWTP process water. This "completely-mixed, continuous-flow" system mimics the IWTP fluid retention times, biomass concentrations, aeration rates, mean cell retention times, and clarifier functions as closely as can be reasonably achieved on a laboratory bench-scale. Influent, effluent and activated-sludge monitoring involves a) TOC and COD analysis; b) nitrate, nitrite, ammonia, sulfate, and phosphate ion determinations; c) mixed-liquor-suspended-solids (MLSS), sludge settling velocity (SSV), sludge volume index (SVI), dissolved oxygen (DO), and specific oxygen uptake rate (SOUR) determinations; d) pH, flow rate, and sludge recycle rate monitoring; and finally e) high performance liquid chromatography (HPLC) and ion chromatography (IC) monitoring of targeted substrate concentrations. It can be seen that the Stage II experiment is more sophisticated than the Stage I shake-flask experiment.

The TOC concentration is a quantitative measure of the total amount of organic carbon being put into the system. The TOC value is important in determining the ratio and amount of essential growth nutrients available for microbial utilization. The TOC value is used to calculate the efficiency of carbon removal by the activated-sludge system and was determined by UV-persulfate oxidation methodology.

The COD is a semi-quantitative measure of the amount of oxidizable carbon in a sample. The COD value is important because it is regulated by the Kelly AFB IWTP NPDES permit. The COD value is used to calculate the efficiency of waste treatment by the activated-sludge system. The COD value was determined by using pre-made HACH COD digestion vials.

The substrate is defined as any single or multiple mixture of new organic chemicals to be tested as a food source for the activated-sludge. Initially, the substrate was added into the influent process water at a low concentration (50 ppm), with enough dilution to prevent toxic effects but sufficiently concentrated to stimulate catabolic activity. After acclimation, the substrate concentration was increased to the point where the effluent quality failed NPDES standards from overloading or the toxic effects of high concentration. The ethylenediamine concentration in the influent and effluent was determined by IC using a conductivity detector. The *m*-nitrobenzoic acid concentration in the influent and effluent samples was determined by HPLC using a UV detector.

Nitrogen is a critical nutrient for microbial growth, as well as an important effluent pollutant. Therefore, determination of the nitrate, nitrite, and ammonia nitrogen concentration was needed because all of these forms of nitrogen are interconvertable in the nitrogen cycle. Quantitation of the amount of nitrogen entering a system is important for maintaining the proper carbon to nitrogen ratio. Additionally, quantitation of the amount of nitrogen leaving the system in the effluent is important because nitrogen in the forms of nitrate and ammonia are regulated by the NPDES permit. Influent and effluent nitrate, nitrite, and ammonia was determined using IC. This analytical detection method was used because the wastewater matrix affected the colorimetric assays previously intended for use. An attempt was made to

determine the influent and effluent Kjeldahl nitrogen concentration; however, technical difficulties were encountered with the HACH procedure and the data obtained was in question. The RESULTS section of this report is lacking the Kjeldahl data but it was felt that the rest of the data overwhelmingly supports the conclusions.

Phosphates and sulfates are also important nutrients for microbial growth. It was not expected that phosphates were going to be limiting, but periodic phosphate determination is needed to verify this assumption. It is important to monitor both sulfates and phosphates to insure that no malignant effects to biological activity arise due to limiting or excessive concentrations of these two nutrients. Both sulfates and phosphates were determined using IC.

The dissolved oxygen concentration of the activated-sludge was tested because oxygen is a critical rate-limiting nutrient in aerobic systems. The activated-sludge respirometric response was also tested to provide a measure of the biological activity of the culture. The dissolved oxygen concentration and respirometric response was used to determine when a chemical produced a toxic condition in the biological processes.

Activated-sludge parameters such as MLSS concentration, SSV, SVI, and mean cell retention time were also determined. These are parameters used to maintain an activated-sludge treatment system at optimal performance conditions. A manual sludge recycle was incorporated into the experiment in order to mimic sludge recycle conditions found at the IWTP. Plate count assays were conducted to determine the population distribution of microorganisms in the activated-sludge. Microorganisms were isolated and sent to an independent laboratory for identification by fatty acid analysis.

The MLSS concentration is a qualitative measure of the density of biomass in an activated-sludge system. Biomass concentrations of 4000 to 6000 mg per liter have been established as the densities needed to provide peak activated-sludge performance. The SSV is also a qualitative measure of biomass density. A dense floc is desired because it contains active biomass, settles quickly, and provides for good clarification of solids and recovery of

the biomass. A light floc is undesirable because of poor separation and inadequate treatment. Unfortunately, a floc which is too dense can be indicative of an old sludge which does not contain many viable microorganisms and may lead to oxygen starvation within the floc. Standard settling velocities have been accepted and used by IWTP operators nationwide. These velocities vary from sludge to sludge but should be between 0.8 and 1.6 inches per minute (2.03 and 4.07 cm per minute), or 4 to 8 feet per hour (1.2 to 2.4 meters per hour).

The SVI is another measure of sludge density and is defined as that volume of activated-sludge needed to provide 1 gram of biomass solids. The sludge volume index is a characteristic of sludge separability and thickening, and can impact clarifier functions. An SVI of less than 100 is normal for most activated-sludges.

A test for phenol was also done because phenol is a principal organic species found in the Kelly AFB IWTP influent. The concentration of phenol must be closely monitored because of its toxicity and treatment priority. It is important to establish that the introduction of a new organic species will not interfere with the treatment of phenols (i.e., mutually exclusive degradation pathways). The introduction of ethylenediamine and/or CLEPO 204 was not expected to inhibit phenol treatment and this was verified through experimentation.

The extent to which the experiments were limited in complexity and size was determined by the Kelly AFB IWTP. The rationale follows that to pursue a degree of experiment complexity beyond that of the IWTP would be a waste of resources. The next step up in complexity would have involved more stringent monitoring of all of the influent, effluent, and activated-sludge parameters mentioned above. This would also have included more stringent monitoring of the kinetics of substrate removal, carbon dioxide production by the biomass, and biomass health [Adenosine triphosphate (ATP) or Nicotinamide adenine dinucleotide phosphate (NADPH) analysis, in addition to respiration rates]. It also would have probably required a complete characterization of the influent waste stream matrix. More rigorous control of sludge recycling and pH adjustment would also have been required. However, this level of

complexity was felt to be too extensive for this program. The interest is in obtaining only that information which allows justification of the next step towards providing on-line treatment.

3. Literature Search

While the Stage I and Stage II laboratory experiments were being conducted, literature search activities were also being pursued to enhance background knowledge. Data and information obtained from a literature search is used to assist in the process of evaluating experimental data and making recommendations. The literature search was designed to obtain information about the waste treatment processes used at the Kelly AFB IWTP, its history and function. This information included, but was not limited to, data concerning average flow rates for the facility, the design of the facility, what types of wastes (chemicals) are treated at the facility, the treatment schedule, and what facilities and equipment exist at the IWTP to analytically monitor the treatment processes. Further literature searches obtained all available information on noncyanide metal stripping products, their chemical components, manufacturer product bulletins, and any information existing in the scientific literature which points to the inherent ability, or recalcitrance, of the organic components in the strippers to be biodegraded.

4. The Kelly AFB IWTP

Since the "raw" waste stream is receiving untreated industrial organics from building 301, then the central aerobic activated-sludge became the target of the studies to determine what effects ethylenediamine and spent CLEPO 204 solutions would have upon biological activity and effluent wastewater quality. The primary focus of this assessment was to determine the impact, whether benign or malignant, newly introduced organic chemicals would have upon the biological treatment processes of the central waste stream. This strategy was followed since this particular biological treatment process is the critical process subject to upset and failure when a new organic chemical is introduced into the waste stream from buildings 301 and 360.

If any organic compound is to be tested for biodegradability potential and treatment compatibility at the Kelly AFB IWTP, then the uniqueness of the IWTP needs to be taken into consideration. When a chemical is targeted for implementation into upstream refurbishing facilities, the effects this chemical has upon all the waste treatment processes at the Kelly AFB IWTP must be assessed in order to insure proper chemical and biological treatment and to prevent treatment system failure. This logic also applies to any chemical currently being discharged to, or targeted for future disposal at, the IWTP facilities which does not fall within the initial intended treatment design of the IWTP (e.g., fire fighting foam, terpenes, diesel fuel, JP4, etc.). Many products, whether they be paint strippers, metal strippers, cleaners, or degreasers claim to be biodegradable by the manufacturers product bulletin, but biodegradable where? In what system? Under what conditions? Also, if a product is targeted for implementation into upstream production facilities, IWTP treatment ability can only be validly defended from the standpoint of actually testing the biodegradability and compatibility of that product under conditions which exist at the IWTP.

It should be noted that the biological waste treatment method developed for the Kelly AFB IWTP is a generic technology applied to a unique situation. While the inherent chemical properties of a chemical remain the same, the waste stream and the microbial population uniqueness of each location needs to be considered. This is why the treatment results obtained at the Kelly AFB IWTP cannot be directly applied to the Tinker AFB IWTP or any other site. In each case, complete testing will have to be done for each waste treatment complex.

5. Stage III Pilot-Scale Testing

The third stage of experimentation (targeted for FY-92) shifts to pilot-scale testing. This activity is a step up in volume from the bench-scale continuous-flow bioreactor experiment but not necessarily one of significant complexity. Pilot-scale testing is labor intensive and the next to the last step prior to implementation. Since the pilot-scale experiments draw reasonably close to actual conditions which exist at the IWTP, they can provide justification to proceed to full-scale on-line testing and eventually

to the final goal of implementation. The most logical tests to be performed on a pilot-scale would involve multi-component substrate testing. Any difficulties which would be experienced with multi-component substrates would have been uncovered during bench-scale bioreactor experimentation; however, if difficulties are encountered then mono-component pilot-scale testing could be done to identify the problem.

The results obtained from pilot-scale testing will provide the Kelly AFB IWTP personnel with data, recommendations, and an operational method by which to treat noncyanide metal stripping waste solutions while maintaining compliance with the NPDES requirements.

Although only those chemicals which are being introduced into the system by the NCYS and DNCYS Programs are being targeted, the testing model which has been developed here can be used to determine the effects of any chemical either currently in the system, or targeted for future discharge to the IWTP facility.

D. COLORED WASTEWATER

When Phase I of the NCYS Program started, the principal source of the "red water" was the waste generated in metal stripping operations using the Air Force C-106 process. The C-106 process uses aqueous solutions of sodium cyanide, sodium hydroxide, and sodium *m*-nitrobenzenesulfonate to strip nickel, copper, silver, and other coatings from ferrous alloys at 55°C (130°F). Since the start of the program, other commercial strippers have also shown the undesirable characteristic of turning dark red. The variables that are consistent between all observed sources of "red water" seem to indicate that nickel stripping in the presence of an alkaline solution of sodium *m*-nitrobenzenesulfonate (or other nitroaromatic) will yield a red colored solution.

Test results from Phase III of the NCYS Program have shown that the reaction of sodium *m*-nitrobenzenesulfonate in alkaline cyanide solutions yields a myriad of products. The organic chemistry of that particular

reaction has been investigated and has shown that the chemistry of nitroaromatic compounds undergo a number of reactions. The products from the reaction can be the result of nucleophilic or electrophilic substitution, hydrolysis, or a combination of the two. If nickel metal is introduced into the equation, then reduction reactions can also occur. One of the possible products from reduction is an azo compound which may result from reductive nitrogen-nitrogen coupling. It has long been known that aromatic azo compounds are highly colored and have been used as dyes for decades. This seems the most likely explanation for the development of the "red water".

SECTION III EXPERIMENTAL PROCEDURES

A. STRIPPING TEST FACILITY

The generic nickel stripper testing was conducted in the Field Test Facility that had been constructed southeast of the Kelly AFB plating shop (building 301) during Phase II of the NCYS program. The facility allows a large number of stripper solutions to be screened for stripping effectiveness and basis metal protection. The laboratory can be used to test small volumes while the process room can be used for testing larger volumes of stripping solutions. In this way, the process room functions as a bridge between test conditions within the laboratory and those encountered in the plating shop. For more specific information, including the floorplan, see the NCYS Program Phase II Final Report (ref. 2).

B. NONCYANIDE METAL STRIPPER IMPLEMENTATION TEST PROCEDURES

1. Metalx, Inc. B-9 Nickel Stripper

Aircraft engine parts which were coated with either electrolytic nickel, or electroless nickel, or nickel-cadmium were used in the evaluation of the B-9 Nickel Stripper. Stripping tests were coordinated with an Air Force chemist and performed at the plating shop located in building 301 on Kelly AFB. The implementation consisted of selecting representative parts, recording all pertinent information, and monitoring the process for nickel stripping and basis metal protection. A stainless steel process tank (capacity 500 gallons) was chosen for its compatibility with the stripper constituents and was equipped with cross-flow ventilation.

This commercial stripper is a proprietary mixture of solid components which is dissolved in water to generate the stripping solutions. The product bulletin and Material Safety Data Sheets (MSDS) are presented in Appendix A.

Since the stripper contains only solid components, solution agitation utilized an air sparge while the temperature was maintained with a teflon coated steam heating coil. The addition method for solution preparation and operation was used according to instructions supplied by the manufacturer. This method was selected since it was considered to be best suited for the continuous stripping operations encountered at Air Force plating shops. The addition method starts with a less concentrated initial stripping solution and requires addition of new stripper whenever the stripping rate falls below the desired level.

Aircraft parts were processed using the same cleaning and rinsing procedures in use at the plating shop. A list of the parts used for the testing of Metalx B-9 is given in Table 2. Before immersion, the larger parts were suspended from stainless steel hooks, while the smaller parts were loaded into stainless steel wire baskets. These parts were then immersed in the solution and inspected every three to four hours for stripping efficiency. The inspection for nickel stripping and rinsing properties was performed after completing the rinsing process. The parts were then put back into the production line and reevaluated, after cleaning, for basis metal protection. The loading capacity of the strippers was determined by continued usage of the solution until stripping was no longer effective. At this time, the stripper was regenerated to extend solution lifetime and regeneration was continued until no longer effective. This length of time is termed the stripper's life expectancy. The bath's life expectancy, coupled with the cost of maintenance and initial makeup, can be used to determine the economic benefits of using noncyanide strippers when compared to their cyanide counterparts. What also needs to be considered in the economic analysis is the cost for disposal of the stripping solutions after they cease to function. In the results section of this report, we will attempt to relate the benefits achieved with noncyanide strippers with respect to stripping rate, basis metal protection, worker safety, and disposal costs.

TABLE 2. AIRCRAFT PARTS USED IN IMPLEMENTATION TESTING OF METALX B-9.

| | |
|---|----|
| F-100 Engine Parts: | |
| Bracket assembly, bleed valve | 84 |
| Plate assembly | 25 |
| Nuts, brg. retainer | 27 |
| Bushing assembly | 19 |
| T-56 Engine Parts: | |
| Compressor wheels | 66 |
| Tie bolts | 25 |
| Bolts, shear | 7 |
| Shaft, propeller | 34 |
| Seals, labyrinth | 8 |
| TF-39 Engine Parts: | |
| Bolts, coupling | 20 |
| Nuts, coupling | 15 |
| Turbine wheels | 15 |
| Thrust bearings, lock propeller | 22 |
| G T Engine Parts: | |
| Breech caps | 17 |
| Turbine wheels | 76 |
| B-52 Parts: | |
| Engine mount | 12 |
| Bolt cones | 17 |
| Lock pins | 10 |
| Supports | 14 |
| Brackets | 39 |
| C-5 Parts: | |
| Brackets | 14 |

Parts Total = 566

2. McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper

Silver plated parts were used for the evaluation of Rostrip 999-SP. Because silver is not routinely stripped at Kelly AFB, there was a recurring problem of obtaining parts for use in implementation tests. The operating solution volume was 100 gallons and utilized a polypropylene tank. The solution was agitated using an air sparge and the temperature was left at summer ambient temperatures (approximately 32°C, 90°F).

The electrolytic stripping of silver coated parts was performed in the following manner. The parts were attached to stainless steel hooks which were in turn suspended from a copper anode bar that stretched across the top of the tank. The cathode was made out of stainless steel and was suspended in

the tank. A Dynapower rectifier, rated to 15 volts and 25 amperes, was used to supply the electric current. Since electrolytic stripping tends to be highly aggressive, the parts were inspected for stripping performance every 15 minutes. A list of the parts used in the implementation is given in Table 3. As with the B-9 Nickel Stripper, parts were inspected for basis metal attack after completing the standard rinsing procedures currently used in the plating shop.

TABLE 3. AIRCRAFT PARTS USED IN IMPLEMENTATION TESTING OF ROSTRIP 999-SP.

TF-39 Engine Parts:

| | |
|-------------------------------------|----|
| Nuts, spanner | 10 |
| Nuts, split | 9 |
| Nuts, coupling | 12 |
| Seals, labyrinth | 10 |
| Tubes, adapters LPT & HPT | 26 |
| Bolts, coupling fan HPT | 4 |
| Bolts, coupling fan LPT | 4 |
| Adaptor, HPT rotor | 2 |

T-56 Engine Parts:

| | |
|--|----|
| Shaft, propeller | 12 |
| Gear, sun | 8 |
| Gear, spur | 6 |
| Hub, sun gear | 2 |
| Hub Flange, sun gear | 2 |
| Shaft Assembly, alter drive | 3 |
| Shaft Assembly, hydraulic pump drive | 3 |
| Sleeve, oil inlet | 8 |

F-100 A/C Engine Parts:

| | |
|-------------------------|----|
| Nuts, Bearing | 3 |
| Idler Gears | 10 |

C-5 Aircraft Parts:

| | |
|--------------------|----|
| Bushings | 10 |
|--------------------|----|

Parts Total = 144

C. FIELD TEST PROCEDURES FOR NONCYANIDE METAL STRIPPERS

The generic nickel stripper was field tested using operating volumes of 10 or 15 gallons, with the temperature varied from 45 to 66°C (110 to 150°F).

The pH testing was included in the formulation process because nitric acid is a component of this stripper and is used at make-up to prepare a solution in the desired pH range. Testing of the longevity solution was performed weekly; it started at initial make-up and continued for 2 months. Loading tests were performed at 1 ounce per gallon intervals until the stripping rate for electrolytic nickel fell below 1 millinch per hour. At this point the solution was regenerated, tested for regeneration effectiveness, regenerated a second time, and tested again. The solution was then loaded again and the final determination of nickel stripping rates and basis metal protection of a fully loaded solution was made.

1. Test Materials

The electrolytic and electroless nickel stripping rates for the generic stripper were determined using coupons of low alloy steel which had been plated with the appropriate metal. The electrolytic nickel coated coupons ordered this year were returned because they were defective. This forced us to use the same coupons that were used for last year's tests. The used coupons were refurbished by removing the surface layer of the plate material by immersing the coupons into used generic stripping solutions left from the early pH tests. The standard cleaning procedure, discussed below, was then used to prepare the coupons for testing. The electroless nickel coupons appeared acceptable at the time of receipt; however, none of the strippers we tested were able to remove the plate. This lack of stripping forced us to use last year's coupons for testing both nickel plates. The corrosion effects of this stripper were determined using the following types of materials: 17-4PH, 316, and 410 stainless steels; C4340 and D6AC low alloy steels; Haynes 188 cobalt alloy; and Inconel 718 nickel alloy.

2. Coupon Preparation and Cleaning

The basis and plate metal coupons were prepared for testing in the following manner. Each coupon's height, width, thickness, and hole diameter were measured at three different locations to obtain average dimensions. The average values were then used in the calculations to determine the stripping rates. Since the coupons needed to be scrupulously cleaned, gloves were worn

during all of the operations. Basis or plate metals were cleaned with soapy water, rinsed with tap water to remove the soap film, rinsed with deionized water, and immediately dried. The coupons were then wiped with a cloth soaked in isopropyl alcohol. The nickel plated coupons were immersed in a 1:1 mixture of concentrated hydrochloric acid and water for about 20 seconds, thoroughly rinsed with deionized water, and dried. All coupons were dipped into acetone and then placed in an oven at 50°C (120°F) for 30 minutes to dry. When dry, the coupons were removed from the oven and placed into a desiccator to cool to room temperature. The weight of each coupon was then measured to the nearest tenth of a milligram (0.0001 g) using a Sartorius analytical balance. Since the coupons were made out of iron and nickel, magnetic interference was encountered while weighing the coupons. This interference was overcome by weighing the coupons on top of a tared 50 mL beaker.

3. Plate Metal Stripping Rates and Basis Metal Protection Determination

The testing was performed by hanging the previously measured and cleaned coupons from stainless steel hooks and immersing the test materials into the solution. Immersion times for the plate metals were one hour for the electrolytic nickel and two hours for the electroless nickel coupons, while the basis metals were immersed for twenty-four hours. At the end of the test, the plated coupons were rinsed with water, scrubbed with a soapy abrasive cloth to remove all smut, rinsed with deionized water, and then immediately dried. They were next wiped with a cloth soaked in isopropyl alcohol, dipped in acetone, then dried in an oven at 50°C for 30 minutes. After removing from the oven, the coupons were placed in a desiccator to cool before weighing. The basis metal coupons underwent the same cleaning procedure, except scrubbing was not necessary, and immediate drying was necessary since the low-alloy steel coupons would develop stains within seconds after exposure to the air while wet. After obtaining each coupon's weight, the surface was analyzed for pits and stains. Changes in mass and surface characteristics were recorded to determine the performance characteristics for each stripper, as reported in the results section of this report.

All data was entered into a computer program using a Lotus 1-2-3 spreadsheet to calculate the surface areas and stripping rates.' The use of a

computer to perform the calculations offered better accuracy by reducing or eliminating errors. These Lotus spreadsheets are presented in Appendices C through G.

4. Generic Stripping Solution Preparation

The generic stripper used in the field tests was prepared in the following sequence of steps:

1. The tank was filled one-third to one-half full of deionized water.
2. Sodium *m*-nitrobenzenesulfonate (10 percent by weight) was added to the tank with stirring.
3. Concentrated nitric acid was added (7 percent by volume) quickly to the mixture. This addition resulted in a minor amount of fizzing (probably from reaction with sodium carbonate impurity in the sodium *m*-nitrobenzenesulfonate), and the solution color changed from medium orange to pale yellow.
4. Ethylenediamine was then added (20 percent by volume and using good ventilation) slowly to the solution. The addition must be made slowly since the solution heats up rapidly. This heating is the result of ethylenediamine neutralizing the acid in solution and also because ethylenediamine forms a hydrate. This is an exothermic reaction which requires caution. If the amount of heating needs to be reduced, the ethylenediamine can first be mixed with water (one to one) and then be allowed to cool before pouring into the stripper. If this is done, then the amount of water used in step 1 will need to be reduced to prevent accidental addition of excess water.
5. The solution was allowed to cool, if necessary, to the desired operating temperature. Then sodium thiocyanate was weighed and added all at once.
6. Water was then added to bring the solution to volume.

Before use, the solution was allowed to stir overnight, with heating, to dissolve all solids and to stabilize the temperature. The surface of the solution was covered with a layer of vapor suppression balls in order to help

stabilize the temperature and to help reduce the amount of stripper lost to the atmosphere through vaporization.

5. Temperature Tests

The tests to determine the optimum temperature were conducted using a 15 gallon tank and at the following temperatures - 45, 55, and 66°C (110, 130, and 150°F). The temperature was maintained using thermostat-controlled quartz heaters, while the solution was agitated using mechanically propelled, teflon-coated stir blades.

6. Longevity Tests

Longevity tests were conducted in a 10 gallon container and consisted of heating the solution to 130°F starting at 8:00 a.m. Monday morning and continuously heating the solution until 5:00 p.m. the following Friday afternoon. This resulted in continuous heating of the bath for 105 consecutive hours every week. The stripper was treated in this manner in an effort to mimic the conditions that would normally be encountered while in use at the plating shop on Kelly AFB. Tests to measure the nickel stripping rate and basis metal protection were performed weekly starting the day after initial makeup and lasting for a total of 9 weeks.

7. Nickel Loading Tests

Loading tests were conducted in the same solution previously used for the temperature tests. The solution was loaded with incremental amounts of nickel by dissolving a measured amount of nickel anodes (which contain some sulfur). The solution was loaded in this manner, rather than adding nickel salts, since this procedure more closely resembles what the solution would encounter under extensive use for stripping electrolytic nickel plates. This procedure also prevents introduction of extraneous anions (e.g., nitrate and sulfate) which would accompany nickel in the form of a salt. The resulting nickel concentrations were determined using atomic absorption methods of analysis.

8. Regeneration Tests

Regeneration of the loaded solution was then conducted by addition of components which may have been depleted during the stripping operations. The specific components used in the regeneration process were determined using electrochemical testing. The regeneration was conducted in two stages. Stage one involved addition of ethylenediamine to the solution until the pH was in the same range as the starting solution, then addition of 2.5 percent by weight of sodium *m*-nitrobenzenesulfonate. The second stage was addition of another 2.5 percent by weight of sodium *m*-nitrobenzenesulfonate. Each regeneration was tested using plate and basis metal coupons. The regenerated solution was then loaded with another 1 ounce per gallon of nickel and retested.

D. JAR TEST PROCEDURES

The jar tests were performed using a procedure almost identical to the one reported for the field tests. The coupon preparation and cleaning is exactly the same as that previously discussed in section C-2, above. The operating volumes are the only major difference between the two procedures. Since jar tests utilize only 250 mL of solution, they require specialized glass reactors that were constructed during Phase I of the NCYS Program. These jars will hold two coupons suspended in the stripper, and since all tests were run in duplicate, only one material could be tested at a time. Coupons of the plate material to be tested, either electrolytic or electroless nickel, were suspended in the solution for the required amount of time (either 1 or 2 hours, respectively). The plated coupons were removed and coupons of low-alloy steel then underwent 24 hour tests to determine the extent of basis metal attack. The low-alloy steel coupons were used since they are, in general, the most susceptible to attack. All coupons that completed testing were then cleaned, weighed, and examined using the procedure described in the Field Tests section of this report.

E. ELECTROCHEMICAL TEST PROCEDURES

Electrochemical tests to determine theoretical nickel stripping rates were performed using a Princeton Applied Research Corporation (PARC) Model 342 Galvanostat/Potentiostat with an IBM computer interface, printer, and *SoftCorr* corrosion measurement software. The experimental procedure for techniques used in the electrochemical analysis is contained in the Phase III Final Report (ref. 3). A standard 3-electrode cell was used for all analyses utilizing a Ag/AgCl (saturated KCl) reference electrode and a platinum wire auxiliary electrode. The procedure for maintenance and conditioning of the reference electrode is also contained in reference 3. The test material was fashioned into an electrode by forcing it into a piece of drilled teflon rod, then the end was polished to provide a smooth surface. This procedure for preparation of test electrodes was described previously in the Phase II Final Report (ref. 2). Standard corrosion techniques were used for analysis and included Tafel and Anodic Potentiodynamic Polarization tests. Chemicals were generally of reagent grade and used as received. Purified water (Nano-pure system) was used in the preparation of all test solutions.

F. BIOLOGICAL TEST FACILITIES

The biological experiments were conducted in the facility that was constructed west of the Industrial Waste Treatment Facility (building 621) during Phase III of the NCYS Program. This trailer houses a complete biological testing laboratory and office. On a platform northeast of the trailer is the pilot-plant facility. The pilot-plant facility was designed to use activated-sludge cultures and IWTP process water. It is also on a larger scale than the bench top bioreactor and was meant to bridge the gap between laboratory studies and full-scale incorporation into the waste treatment facility. For more details concerning the trailer and pilot-plant facilities, including floorplans and schematics, consult the NCYS Program Phase III Final Report (ref. 3).

G. BIOLOGICAL TEST PROCEDURES

1. Stage I Biodegradability Test Using Spent Clepo 204 as a Substrate

This 72 hour acclimation test is a modified form of the ASTM procedure D 2667-82 as discussed in reference 3. The procedure is designed to determine if a microbial population is able to utilize a particular carbon source given adequate time for enzyme induction and population proliferation to occur.

a. Precipitation of Heavy Metals from Spent CLEPO 204

The spent CLEPO 204 solution retrieved from the plating shop contained 5 to 7 percent nickel (5,000 to 7,000 ppm). All of the heavy metals, including nickel, needed to be removed (because of toxicity) prior to using the solution as a carbon source. The following procedure is a representation of the treatment a heavy metal laden waste stream would be subjected to while being processed at the IWTP metals precipitation pre-treatment facility. The only deviation is that the IWTP neutralizes the waste to pH 7.0 after filtration.

A sample of spent CLEPO 204 nickel stripping solution was obtained from the plating shop (building 301). Some of this solution (250 mL) was pipetted into a 500 mL beaker. Concentrated sulfuric acid was added until the pH was 2.5 or lower. Sodium meta-bisulfite (1.5 g) was added and the solution was allowed to stir for 30 minutes. Sodium hydroxide (50 percent by weight) was then added to raise the pH to 9.5 or higher. Solutions of ferrous sulfate (21 mL of a 2 Molar solution) and sodium sulfide (10.4 mL of a 5 Molar solution) were added and the solution was allowed to stir for 5 minutes. After stirring, cationic/anionic polymer (1 mL) was added. The solution was filtered through a 0.45 μm glass fiber filter and analyzed by (HPLC) and Inductively Coupled Plasma emission spectroscopy (ICP) to determine the concentration of *m*-nitrobenzoate and nickel, respectively.

b. 72 Hour Shake-Flask Tests

A sample of Sterile Environmental Protection Agency (EPA) Minimal Media (ref. 3, 100 mL) was placed in each of four sterile 250 mL Erlenmeyer flasks. Flask #1 was spiked with 372 ppm ethylenediamine and 124 ppm *m*-nitrobenzoate. Flask #2 received 474 ppm ethylenediamine and 158 ppm *m*-nitrobenzoate. Flask #3 received 555 ppm ethylenediamine and 185 ppm *m*-nitrobenzoate, and flask #4 received 563 ppm ethylenediamine and 187 ppm *m*-nitrobenzoate. Activated-sludge (5 mL) from the IWTP was added to flasks #1, #2, and #3; flask #4 was used as the sterile control. All four flasks were incubated at 30°C (86°F) with shaking for 2 days (48 hours). After 2 days, 5 mL aliquots from each flask were placed into fresh media of the same ethylenediamine and *m*-nitrobenzoate concentration. These flasks were then incubated for another 24 hours. After 3 days (72 hours) a 5 mL aliquot was removed from each flask and placed into fresh media of the same ethylenediamine and *m*-nitrobenzoate concentration. The flasks were incubated with shaking. Samples were removed after 0, 24, 48, and 72 hours and analyzed by HPLC to determine the loss of *m*-nitrobenzoate over time.

2. Stage II Bench-Scale Continuous-Flow Bioreactor Tests Using Ethylenediamine and Spent CLEPO 204 as Substrates

a. Bioreactor Set-up

The bench-scale continuous-flow air-lift bioreactor consists of a 4 inch diameter by 28 inch (10 cm by 71 cm) long piece of polyvinyl chloride (PVC) pipe of 5.7 liter total volume, 4.5 liter working volume, attached to a square baseplate. The column is equipped with an air inlet (300-400 mL per minute), an influent feed inlet, and a gravity overflow control which maintains a constant liquid level in the reactor. The air inlet contains a porous Teflon frit which disperses the air into tiny bubbles. This increases the efficiency of oxygen transfer and provides agitation. The influent process water is stored in a 25 liter carboy and is pumped into the reactor at a set rate. The carboy reservoir contains 12-48 hours worth of influent supply. The influent was collected daily from the IWTP and sampled as described below in section (c). The effluent flowed into a 1 liter beaker

which acted as a clarifier. The activated-sludge which left the bioreactor collected in the beaker. It was then recycled back into the bioreactor manually.

b. Bioreactor Start-Up

Process water from the IWTP was used to fill each of six different 25 liter carboys equipped with pumping attachments. The carboys were numerically labeled from one to six. The influent for carboys #1, #3, and #5 were adjusted to pH 7.0 with hydrochloric acid (conc.) or sodium hydroxide (50% by weight). The remaining carboy influents were adjusted to pH 8.5 with sodium hydroxide (50 percent by weight). The pH was adjusted every sample period throughout the experiment. The influent solution was pumped into each carboy through Tygon tubing. The influent flow rate was adjusted to 14 mL per minute and measured with a graduated cylinder and stop-watch. This flow rate provided a calculated retention time of 5.3 hours for the 4.5 liter working volume in the reactors. A sample (60 mL) of each influent was collected, filtered through a 0.45 μm glass fiber filter, and analyzed for TOC, COD, pH, substrate concentration, phenol concentration, nitrate, nitrite, ammonia, total Kjeldahl nitrogen concentration, phosphate, and sulfate concentration. The sample analysis procedures are described below.

Each of the six bioreactors were numbered from 1 to 6 and filled to overflowing with fresh activated-sludge from the IWTP activated-sludge basin. The influent pump was turned ON and the reactors were allowed to run for 24 hours. Samples were collected every 4-12 hours for analysis. After 24 hours, influent reservoirs #1 and #6 received an initial spike of ethylenediamine, and the pH was adjusted to 7.0 and 8.5, respectively. Samples were then collected every 12-24 hours. After 72 hours, influent reservoirs #2 and #5 were spiked with spent CLEPO 204 (39 ppm ethylenediamine and 10 ppm *m*-nitrobenzoate) and pH adjusted to 7.0 and 8.5, respectively. Columns #4 and #5 were used as controls throughout the experiments.

When the effluent TOC, COD, and substrate concentration data showed that the influent substrate was being biodegraded, the influent substrate concentration for reactors #1, #2, #5, and #6 was increased. When

the effluent data for these reactors continued to show substrate biodegradation, the influent substrate concentration for columns #1 and #6 was continually increased up to 500-700 ppm ethylenediamine.

c. Analysis of Samples

(1) Anion Analysis Method. All pre-filtered samples were analyzed for anions by IC. A DIONEX 8000 series Ion Chromatograph was used to determine concentrations of nitrate nitrogen, nitrite nitrogen, phosphate, and sulfate. An Analytical Module Pump (AMP) was used to pump eluent #1 and eluent #2 through the DIONEX Ion Pac (AS4ASC) column and DIONEX Anion Micro-Membrane Suppressor at a flow rate of 1 mL per minute. Sulfuric acid (0.025 Normal) was used as the regenerant. The flow of the regenerant was set at 4-5 mL per minute and was regulated by pressurization of the regenerant reservoir with nitrogen gas. The concentration of eluent #1 and eluent #2 were 1.7 mMolar sodium bicarbonate with 1.8 mMolar sodium carbonate, and 17 mMolar sodium bicarbonate with 18 mMolar sodium carbonate, respectively. The overall run time was 20 minutes. Eluent #1 was pumped from time 0.0 minutes to 11.5 minutes, then turned OFF. Eluent #2 was pumped from 11.5 minutes to 14.1 minutes, then turned OFF. Eluent #1 was then pumped for the remaining 5.9 minutes as a column reconditioning step.

Standard curves for each anionic species were generated using the AUTOCAL program present in the DIONEX 8000 series software. Standards supplied by DIONEX were prepared and used for calibration. The DIONEX 8000 series data acquisition module recorded the retention time of each anion and calculated the concentration in ppm from the area under each peak recorded by the conductivity detector. Standard curves were updated bi-weekly as recommended by DIONEX.

(2) Cation Analysis Method. All pre-filtered samples were analyzed for ammonia nitrogen and ethylenediamine using a DIONEX 8000 series Ion Chromatograph. An AMP was used to pump eluent #1 and eluent #2 through a DIONEX Ion Pac (CS10) column and a DIONEX Cation Micro-Membrane Suppressor at a flow rate of 2 mL per minute. Eluent #1 was a mixture of 40 mMolar hydrochloric acid with 2 mMolar diaminopropionic acid (DAP) solution, and

eluent #2 consisted of 50 mMolar hydrochloric acid with 20 mMolar DAP. The total run time was 25 minutes. Eluent #1 was pumped from time zero to 1.2 minutes. Eluent #1 was then turned OFF and eluent #2 was pumped until 22.0 minutes. Eluent #2 was then turned OFF and eluent #1 was pumped for the remaining 5 minutes as a column reconditioning step. The regenerant used in the cation analysis was 100 mMolar tetrabutylammonium hydroxide (TBAOH). The regenerant flow rate of 14 mL per minute was controlled by a closed loop DIONEX AutoRegen system. The spent TBAOH was stored in a 500 mL reservoir and pumped through a DIONEX Cation Regenerator Cartridge where spent regenerant (tetrabutylammonium chloride) was converted back to fresh regenerant.

Standard curves for each cation were generated using the AUTOCAL program. Standards were prepared fresh and the retention times and peak areas obtained from the conductivity detector were analyzed by the series 8000 data acquisition module.

(3) m-Nitrobenzoate and Phenol Determination. The detection of these two compounds in aqueous samples was done by reverse-phase HPLC using a 30 cm C-18 column, a KRATOS model 430 mixing module, a KRATOS model 400 dual-piston pump, a KRATOS model 757 UV detector (set at 220 nm), and a Hewlett-Packard HP3394A integrator. After injection of 20 μ L of the sample, the primary solvent (0.1 Molar monobasic potassium phosphate at pH 6.7) was pumped through the column for 5 minutes. After 5 minutes run time, a gradient was formed over the next 10 minutes of run time going from 100 percent of the primary solvent to 100 percent of the secondary solvent (60 percent methanol and 40 percent 0.1 Molar monobasic potassium phosphate at pH 6.7). The secondary solvent was then run for another 10 minutes. After 25 minutes, the secondary solvent was turned OFF and a 7 minute equilibration period occurred using 100 percent of the primary solvent. The total run time was 32 minutes.

Standards were prepared weekly and standard curves were generated using the integrated area obtained from the integrator, and a LOTUS 1-2-3 spreadsheet program.

(4) Total Organic Carbon (TOC). The value for the TOC was determined using a Rosemont-Dohrman DC-80 TOC Analyzer. Pre-filtered samples

to be analyzed (200 μ L) were injected directly into the UV-persulfate digestion chamber. TOC values were recorded as ppm carbon.

(5) Chemical Oxygen Demand (COD). The value for the COD was determined using HACH COD digestion vials. Pre-filtered samples to be analyzed (2 mL) were pipetted into COD vials. The vials were sealed, vortexed, and placed in a 125°C (257°F) incubator for 2 hours. After incubation the vials were removed, allowed to cool, and the COD value in ppm was determined colorimetrically using a HACH DR/3000 spectrophotometer.

(6) Dissolved Oxygen (DO). The amount of DO was determined polarographically using a YSI dissolved oxygen meter and an oxygen sensitive electrode. The probe was calibrated using oxygen saturated water, and DO values were recorded in milligrams of oxygen per liter of solution.

(7) Specific Oxygen Uptake Rate (SOUR). The SOUR, or oxygen consumption rate, was determined polarographically using a YSI Biological Oxygen Monitor and Clark-type oxygen sensitive electrodes. The instrument was calibrated using oxygen saturated water. Oxygen consumption values were recorded as milligrams of oxygen consumed per liter per minute and can be converted to milligrams of oxygen consumed per liter per hour.

(8) Mixed-Liquor-Suspended-Solids (MLSS). The MLSS, or Total Suspended Solids, was determined by drying a 10 mL sample of the activated-sludge at 105°C (221°F) in a pre-weighed crucible. Dried samples were weighed and the MLSS value was recorded in milligrams of solid per liter of solution.

(9) Sludge Settling Velocity (SSV). The rate for the SSV was determined with a stop-watch by monitoring a 1 liter sludge sample contained in a 1 liter graduated cylinder. The sludge blanket height was measured and recorded every 15 minutes for a total of 45 minutes.

(10) Sludge Volume Index (SVI). The SVI was calculated by multiplying the 30 minute settled volume by 1000, then dividing the result by the MLSS value. The results are in milliliter per gram.

(11) Kjeldahl Nitrogen. The Kjeldahl nitrogen concentration was determined using a HACH Digesdahl apparatus and the Nessler ammonia detection method. A pre-filtered sample (25 mL) was pipetted into a 100 mL Digesdahl flask along with 70 percent sulfuric acid (5 mL) and a boiling chip. The flask was placed on a HACH Digesdahl Apparatus [consists of a boiler plate set at 440°C (824°F) and a fractionation column]. The samples were heated until the boiling point of sulfuric acid was reached and visible refluxing of the acid occurred. Hydrogen peroxide (10 mL of 50 percent) was added to the sample through a capillary funnel at to the top of the fractionation column. Excess hydrogen peroxide was then boiled off by heating until all boiling action had ceased. The fractionation column was removed, and the flask was taken from the boiler plate and allowed to cool. After cooling to room temperature, the samples were diluted to 100 mL with deionized water, capped and mixed. This digested and diluted sample was then used for the HACH Nessler Ammonia analysis method.

A sample (10 mL) of the digested and diluted solution was pipetted into a 25 mL mixing graduated cylinder. HACH Total Kjeldahl Nitrogen (TKN) indicator (2 drops) was added and HACH 8 Normal potassium hydroxide was added dropwise until the first appearance of a blue color. This sample was diluted to 20 mL with deionized water. HACH Mineral Stabilizer (3 drops) and HACH Polyvinyl Alcohol Dispersing Agent (3 drops) were added. The sample was diluted to 25 mL with deionized water, the graduate cylinder was capped, and the sample was mixed thoroughly by inverting several times. After mixing, HACH Nessler Reagent (1 mL) was added and the ammonia concentration was obtained using a HACH DR/3000 spectrophotometer and a 25 mL sample cuvette. The spectrophotometer was pre-programmed according to the manufacturer's instructions. A prepared water blank was used to zero the spectrophotometer. The reading from the tested samples were multiplied by a dilution factor of 10.4 to obtain the actual total Kjeldahl nitrogen concentration in ppm for the original sample.

d. Microorganism Population Distribution

Microorganism population distributions were determined by standard serial dilution and plate count methods for activated-sludge microorganisms.

The microorganisms were identified to genus and species via the fatty acid analysis method (results obtained from Microbial Identification Systems Inc., Newark, DE.).

SECTION IV RESULTS AND DISCUSSION

Noncyanide stripper implementation continued during this phase of activity. Two strippers, Metalx B-9 Nickel Stripper and Rostrip 999-SP Electrolytic Silver Stripper were both introduced into the plating shop at Kelly AFB. The field testing of a generic nickel stripper was finished and afforded the best electrolytic nickel stripping rate and basis metal protection of any stripper we have tested. The attempt to formulate an electroless nickel stripper gave mixed results with the final decision to recommend use of the new generic nickel stripper for both types of nickel plates.

A. IMPLEMENTATION OF COMMERCIAL STRIPPERS

1. Metalx, Inc. B-9 Nickel Stripper

Metalx B-9 Nickel Stripper, for stripping electroless nickel plates, was deemed worthy of implementation based upon the positive results obtained from field tests conducted last year. It is a solid commercial product which is dissolved in water to prepare the stripping solution. Since it is a solid, the product has advantages over the ethylenediamine based strippers since it contains no volatile organics. It is formulated from amino acids and therefore boasts unmatched biodegradability potential. However, compatibility tests for this product will still need to be conducted. The reason for this is to insure that excessive effluent nitrates are not generated as a result of biodegradation of the amino acids in the formulation. As with most electroless nickel strippers, the bath is run at the maximum temperature allowed - 60°C (140°F). This is due to the fact that electroless nickel coatings are difficult to remove and require higher temperatures to achieve acceptable stripping rates. The implemented stripper was monitored using the same test coupons used in the field tests and also by monitoring the stripping of aircraft parts as they were processed by the plating shop personnel. The stripping rates obtained using the test coupons gave stripping rates similar

to those obtained during last year's field tests (ref. 3). The data obtained during implementation is compiled in Appendix B.

Implementation testing utilized the addition method as outlined in the technical bulletin provided by Metalx, Inc. This method was chosen since it was reported to provide a longer lifetime for the bath. Unfortunately, this stripper experienced several episodes of overheating due to failure of the plating shop's air compressor. These failures resulted in loss of air agitation to the stripper and subsequent overheating of the solution. Due to these incidents, the bath may have undergone thermal decomposition and the results from implementation testing of this particular batch of solution must be evaluated with a degree of caution. This is because we cannot assume that the same results would have been obtained had the solution not been overheated.

The stripping rates for both nickel coatings, as monitored with test coupons, started at a reasonably high rate (1.0 milliinch per hour for electrolytic nickel and 0.6 for electroless), then fell rather dramatically with increasing bath age, see graphs on page H-1 (Appendix H). After five weeks of operation, another addition of stripper was required. This addition provided regeneration to an acceptable stripping rate (from 0.5 to 0.8 milliinch per hour for electrolytic nickel and from 0.2 to 0.7 for electroless); however, the enhanced stripping rate did not last for more than a week. The next addition also dramatically improved the stripping rate, which again fell rapidly after the first week. This pattern of addition followed by loss of stripper efficiency was repeated for almost a month. Each time a new addition was made, the bath recovered just slightly less than it had for the previous addition. Extrapolating the decline in stripping rate, it is estimated that the bath would provide adequate service for 3 to 4 months before needing to be replaced. In order to provide service for this length of time, an addition of stripper would have to be made every other week throughout the lifetime of the stripper.

Almost all basis metals showed excellent protection for the entire life of the bath. The only problem with corrosion occurred during the twenty-four hour basis metals tests which were conducted the seventh week, see graphs

on page H-2. During this test, a pair of C4340 and D6AC test coupons were noticeably corroded and had a significant weight loss. Two other basis metals in the same bath showed higher than normal weight loss; 17-4PH and the Haynes 188 coupons. These corrosion effects are illustrated by the graph which shows that the low alloy steel corrosion rates are off-scale for the test run near forty days. An explanation for the observed corrosion is that during this particular test, the stripping tank was heavily loaded with engine parts, and as a result, the basis metal coupons may have been in direct contact with the engine parts - or perhaps even underneath them. The fact that this corrosion was only observed in this one test seems to indicate that it was an anomalous result and not indicative of the stripping solution as a whole.

During the implementation period from May 6 to September 6, 1991, 566 aircraft parts were evaluated. This represented a cross section of parts from three different aircraft engines and other aircraft parts which are currently processed at the plating shop. A list of these parts is given in Table 2, which is found in the Procedures section of this report. All aircraft parts used to evaluate this stripper demonstrated good basis metal protection and satisfactory nickel stripping rates. Most of these parts stripped completely in a time of four to eight hours. Only when the stripper had significantly deteriorated did the stripping process take more than eight hours. Other conditions such as heavy buildup of nickel and nickel-base metallized coatings also required more than one eight-hour shift to completely strip the parts. The stripping solution's pH values remained very stable and did not vary more than 0.3 pH units during the evaluation.

Toward the end of the fiscal year, a second batch of the stripper was tested using the same addition method. The data from these tests can be found in Appendix C. The solution was prepared on August 10, 1991 and was monitored through the sixth week of operation. This time the solution was free of any adverse effects from overheating. As a result, stable stripping rates for both electrolytic and electroless nickel were obtained while maintaining excellent basis metal protection, see graphs on page H-3. Based upon extrapolation of the test results, the bath should require regeneration during the 7th or 8th week of operation. It is estimated that this batch of stripper will not require replacement for approximately 6 to 7 months.

2. McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper

Rostrip 999-SP was implemented as a result of positive field test results obtained last year. It is sold in the form of a solid powder which is mixed with water to prepare the operating solution. It contains the following ingredients: sodium nitrate, sodium nitrite, and sodium hydroxide. When it comes time for waste disposal, this solution should be very easy to treat since it contains no organic components. However, the contribution to effluent nitrate levels needs to be investigated. This stripper is an electrolytic process and requires an applied voltage in order to strip silver. Since it is alkaline, it can be used to strip silver from low alloy steel (e.g., C4340 and D6AC), but the field tests determined that it severely attacks both Inconel and Haynes. Since Rostrip 999-SP attacks these high alloy steels, the current process using nitric acid must still be used for those applications. With the combination of these two processes, all applications requiring silver stripping can be accommodated.

The implementation of this stripper has yielded mixed results. As previously stated, this stripper had excellent silver stripping rates (between 8 to 10 milliinch per hour) and gave adequate protection to both low-alloy and stainless steel parts. However, both Haynes 188 and Inconel 718 showed severe etching when used in this stripper. With use, the solution does not remain clear and quickly develops a grayish sludge (probably Ag₂O) which interferes with inspection of parts while the solution is being agitated.

Despite these problems, the silver stripping rate was excellent at all pH's tested. The stripping rate for silver started at 8.5 milliinch per hour at pH 10.0 and achieved a maximum value at pH 11.5 (10.1 milliinch per hour), see data compiled in Appendix D. A further increase in pH to 12.0 only decreased the stripping rate to 8.1 milliinch per hour. The increase in pH was tested to determine if the basis metal attack on Haynes and Inconel could be reduced to an acceptable level. Unfortunately, these two basis metals continued to be attacked at all the pH values tested.

Rostrip 999-SP was implemented on June 14, 1991 into the plating shop at Kelly AFB. During the implementation period of June 14 to September 14,

1991, a total of 144 aircraft engine parts were evaluated. These parts represented a cross section of those that are currently stripped in this production application and are listed in Table 3 (found in the Procedures section of this report). With only a few exceptions, most aircraft parts were successfully stripped within 15 to 30 minutes with no corrosion of the basis metals. Results indicate that this solution works well enough to replace the electrolytic cyanide (C-101) process even though some parts did require longer rinsing times than those processed with the cyanide stripper.

A comparison between Rostrip 999-SP and the Air Force Electrolytic Cyanide process (C-101) was performed, see graphs on page H-4. These test results have determined that the Rostrip stripper is slightly better for stripping of silver than the cyanide bath. However, the basis metal corrosion was increased for all basis metals tested. This was especially true for Haynes 188 and Inconel 718 - both were severely attacked by the Rostrip stripper.

If this bath is to be useful, it must be used in conjunction with the nitric acid stripping bath currently used for stripping stainless and alloy basis metal parts, especially for stripping of silver from Haynes and Inconel parts. The low-alloy steel parts that cannot be stripped in acidic solutions can be stripped using Rostrip 999-SP. At this time, there are no known immersion strippers capable of removing silver plates other than the acidic nitric acid baths. Therefore, from the production viewpoint, the nitric acid bath has unequaled qualities which should help it retain a prominent position in the plating shop.

B. FIELD TESTING OF THE GENERIC NICKEL STRIPPER

Based upon recommendations from Phase III tests of the NCYS Program, one generic electrolytic nickel stripper was targeted for field testing this year. The results of these tests are very exciting since this stripper has shown a better combination of nickel stripping rates and basis metal protection than any commercial product tested previously. The testing criteria was the same as for the other tests - pH, temperature, longevity, nickel loading, and

regeneration. The solution was tested at the following temperatures 43, 54, and 66°C (110, 130, and 150°F); the effects of aging were tested once a week for over 2 months; and the effects of nickel loading were tested in the range of 0 to 37 gram per liter (0 to 5 ounce per gallon) in increments of 7.4 gram per liter (1 ounce per gallon). The final load was tested using the solution that had been previously used in the regeneration tests. The raw data is presented in Appendix E, while graphs showing the effects of temperature, pH, nickel loading and regeneration may be found in Appendix H on pages H-5 to H-10.

1. Formulation and Reformulation

The results from Phase III determined that a formulation consisting of ethylenediamine, nitric acid, sodium nitrate, sodium *m*-nitrobenzene-sulfonate and a small quantity of ammonium thiocyanate would work well at stripping electrolytic nickel deposits. Accordingly, this formulation was scheduled for field testing this year. However, shortly after testing had begun, it was determined that the formulation needed to be altered. This was prompted by the large amount of precipitate that formed when the solution cooled. This precipitation could have hindered the agitation and resulted in a shortened bath lifetime due to increased decomposition from localized overheating within an improperly agitated solution. Another minor concern was the potential release of ammonia by neutralization of ammonium salts.

Electrochemical tests, Tafel and Anodic Potentiodynamic Polarization tests (ref. 3), revealed that sodium nitrate could be eliminated entirely from the formulation. The ammonium thiocyanate could be replaced with the sodium salt in order to remove the ammonia producing agents. Also discovered was that the following components could be reduced in concentration: ethylenediamine could be reduced from 25 to 20 percent by volume, sodium *m*-nitrobenzenesulfonate could be reduced from 15 to 10 percent by weight, and sodium thiocyanate could be reduced from 0.5 to 0.1 percent by weight. Once these improvements were made, the solution was ready for field testing. The pH optimization jar tests were used to further refine the formulation by determining the optimum quantity of nitric acid to add.

It should be noted that the use of ethylenediamine was chosen by its literature precedent for forming effective nickel stripping solutions (refs. 27,28). Unfortunately, its beneficial effects appear to be limited to the electrolytic nickel coatings and not the electroless nickel. It has been reported that amines react with elemental sulfur (ref. 33). This may explain why ethylenediamine works well at stripping the sulfur containing electrolytic nickel deposits.

The pH optimization was also performed during the formulation stage in the development of this stripper. This was due to the fact that the concentration of ethylenediamine, sodium *m*-nitrobenzenesulfonate, and nitric acid all impact the pH of the solution. The results from stripping rate tests indicated that any pH in the range of 10.0 - 10.5 was just about equally effective at stripping electrolytic nickel, see graphs on page H-5. The lower pH's were shown to increase basis metal attack; however, as long as the pH remained above 10, basis metal protection was maintained (see graphs on page H-6). Because of these results, the formulation consisting of 7 percent nitric acid (which gave a starting pH of 10.4) was then used for testing the effects of temperature. This was done even though the solution with 9 percent acid performed slightly better at stripping electrolytic nickel. It was felt that it was more important to keep the solution farther away from basis metal corrosion than it was to slightly increase the stripping rate of the plate metals. The small increase in stripping rate was not worth risking basis metal attack.

2. Temperature Tests

The results of the tests to optimize the temperature showed the expected trend of increasing stripping rate with increase in temperature, see graphs on page H-7. This is similar to what was observed for Metalx B-9 and CLEPO 204. Even at the lowest temperature tested, 43°C (110°F), the stripping rate for electrolytic nickel was still very good at almost 2.5 milliinch per hour. While at 65°C (150°F), the same stripping rate skyrocketed to almost 5 milliinch per hour. This stripper has shown a higher electrolytic nickel stripping rate than any of the other alkaline strippers we have tested. The electroless nickel coupons tested during this stage showed no stripping at

all. This was because of anomalous test results obtained using the coupons purchased this year (discussed below). The alkaline pH is important since it is necessary to afford complete protection to low alloy steel basis metals. In fact, this stripper offers excellent protection to all of the basis metals tested.

3. Longevity Tests

If one examines the graphs for the longevity tests (page H-8), one notable feature is the introduction to testing of the electroless nickel coupons which were used for last year's tests. These coupons have been labelled as Ni-P* while the coupons new this year have been labelled Ni-P". The coupons received this year show a marked defiance to stripping with any stripper we have tried; including Metalx B-9 and CLEPO 204. In fact, the stripping rate of the older electroless nickel coupons is ten to a hundred times greater than that observed with the coupons obtained this year.

The question arises as how to justify using the results from one set of coupons over another. The simple response would be that the old coupons show stripping while the new ones do not; if you want to determine a stripping rate, you need coupons that have a measurable stripping rate. One possible explanation for the stripping of one set of coupons and not the other may be the quantity of phosphorus in the plates. It is known that nickel plates with a higher phosphorus content are harder, more brittle, and more difficult to remove. The coupons received this year may have an unacceptably high phosphorus content, but this can only be determined by analysis. This question of plate material composition is an important one, especially for electroless nickel, and needs to be addressed in the future. It will need to be determined what the capabilities and limitations of the generic stripper are toward stripping the various types of electroless nickel plates that may be encountered in the plating shop. In particular, what percentage of phosphorus in the nickel plate causes the generic stripper to stop working. This question will become increasingly more important since high-phosphorus electroless nickel plates have been touted as alternatives or outright replacements for a number of plate materials and applications, including hard chromium.

The longevity test results have shown that the initial stripping rate for electrolytic nickel was about 3.7 milliinch per hour - an extraordinarily fast stripping rate. This rate remained above 3 milliinch per hour for almost a month, see graph on page H-8. The heating of the bath for 5 consecutive days and nights, every week for almost a month, showed a steady and slow decrease in the stripping rate of the solution. After two months, even with this steady decrease, the stripping rate was still excellent at over 2.5 milliinch per hour. It appears that after the first month's decrease in stripping rate, the rate seems to level off at around 2.5 milliinch per hour. There was not enough time to test beyond the 9 weeks; however, it may be that the solution has reached a point where it maintains its stripping rate for extended periods of time, perhaps even months.

The stripping rate for the electroless coupons has remained almost constant for the 6 weeks they were tested (also from graph on page H-8). The reproducibility of the stripping rate tests appear to be questionable since the stripping rate, as the graph shows, fluctuates around 0.55 milliinch per hour. It reached a maximum of 0.64 and a minimum of 0.45 milliinch per hour with no general trend between these values.

The continuous heating of the bath appears to have an effect on the pH. This is important to note since the pH should not be allowed to fall below 10.0 in order to maintain basis metal protection. During testing, the pH fell below 10.0 only after 8 weeks of testing. Before continuing the tests, the pH was restored by addition of ethylenediamine. The pH was originally restored to 10.4 upon addition of 2.5 liters (6.5 percent total volume) of ethylenediamine, but heating the solution for the next three days decreased the pH to 10.2. This pH was used for the final longevity test. This increase in pH may be due to the loss of ethylenediamine through vaporization. If this is the case, it might be better to adjust the pH with sodium hydroxide instead.

The basis metals used in the longevity tests showed no signs of pitting, etching, or even staining until the pH fell below 10.0 (see graph on page H-8). At this pH there appeared a series of tiny pits in a band on one of the Inconel 718 and one of the Haynes 188 coupons. The basis metals are

all tested in duplicate and only one of each pair of these basis metals showed any adverse affect. During the last test, one of the 17-4PH coupons showed similar behavior. This was puzzling since only one coupon in each pair showed the effect. Since the longevity tests were conducted in a 38 liter (10 gallon) container, it may be that the coupons showing the pits were in close proximity to the stir blade and may have been pitted by debris in the solution impacting the surface of the coupon. In general, the basis metal coupons all showed remarkable stability in this stripper, and the mild staining that was occasionally encountered on the low alloy steels coupons (C4340 and D6AC) may have resulted from exposure to moist air during coupon preparation and cleaning. With the exception of the three coupons mentioned above, all other basis metals showed exceptional protection to corrosion during all 24 hour immersion tests conducted.

4. Loading Tests

The tests to determine the effects of nickel loading were conducted at 7 gram per liter (1 ounce per gallon) increments. The results are depicted in the graphs on page H-9 and demonstrate the expected trend of decreased stripping rate with increased nickel loading. The decrease is almost linear between 7 and 30 gram per liter (1 and 4 ounce per gallon) of nickel. If one extrapolates from the line, the stripping rate appears to fall below 1 milliinch per hour at about 24 gram per liter (3.2 ounce per gallon) of nickel. However, with regeneration, the nickel concentration responsible for decreasing the stripping rate to less than 1 milliinch per hour can be greatly increased.

Basis metal protection was preserved during all loading tests. This suggests that there are no deleterious by-products generated by the stripping reaction that could initiate corrosion of the basis metals. Electroless nickel plates were also tested and showed stripping rates of around 0.25 milliinch per hour. These rates were lower than those obtained with the longevity tests, as would be expected with a loaded solution.

5. Regeneration Tests

Electrochemistry was used to determine which chemicals could be added to the loaded solution in order to regenerate the stripper. It was suspected that ethylenediamine would need to be added since it is a strong base (reacting with carbon dioxide in the air) and because it is potentially volatile (evaporating out of the solution). It was determined that addition of ethylenediamine or thiocyanate did increase the nickel stripping rate, but only slightly. The most dramatic increase in stripping rate was observed upon addition of sodium *m*-nitrobenzenesulfonate. This would seem to support the hypothesis that the aromatic nitro group is functioning as an oxidizing agent toward the nickel in the plate materials and facilitates removal of the coatings.

The regeneration tests were conducted in two stages. It appears that the first regeneration had the most profound effect on the stripping rates. The first stage involved addition of ethylenediamine until the solution pH was about 10.4 and then 2.5 percent by weight sodium *m*-nitro-benzenesulfonate was added. The solution was tested and this combination of ingredients served to restore the solution pH to 10.6, and the electrolytic nickel stripping rate to over 1 milliinch per hour (see graphs on page H-10).

This first regeneration may have used more ethylenediamine than was necessary since the solution smelled strongly of ethylenediamine for several days. This strong smell seemed to indicate that an increased amount of ethylenediamine was being lost through vaporization. One function of the nitric acid is to protonate the ethylenediamine and reduce the solution pH; however, this process also reduces the vapor pressure of the organic amine. A possible solution to this problem would be to attempt the regeneration by adding a mixture of ethylenediamine and nitric acid to restore the concentration of ethylenediamine, then adjusting the pH with sodium hydroxide.

The solution was then regenerated with a second addition of sodium *m*-nitrobenzenesulfonate (2.5 percent by weight). This second regeneration only slightly increased the electrolytic nickel stripping rate from 1.3 to 1.4 milliinch per hour. The nickel stripping rate was maintained at almost one

milliinch per hour even after the solution was loaded with another ounce per gallon of nickel. This meant that even with 37 gram per liter (5 ounce per gallon) of nickel, the stripping rate was still almost 1 milliinch per hour for electrolytic nickel. The electroless nickel stripping rates were also increased by the regeneration and showed recoveries from 0.17 to 0.27 milliinch per hour. This stripping rate showed only a slight decrease to 0.25 milliinch per hour in the 37 gram per liter (5 ounce per gallon) loaded solution.

C. DEVELOPMENT OF GENERIC ELECTROLESS NICKEL STRIPPERS

1. Electrochemical Tests

The electrochemical testing of electroless nickel strippers was continued from the past year. There were a number of individual components and formulations tested. One key ingredient for these strippers appears to be the addition of an aromatic nitro compound. Sodium *m*-nitrobenzenesulfonate was chosen for use since it appears to work exceptionally well for nickel stripping applications and is relatively inexpensive. Since it is already approved for use in several Air Force processes, including the C-106 cyanide immersion stripper, procurement should be a fairly simple matter. This aromatic nitro compound must function to oxidize the nickel plate material since regeneration testing (see section B-5, above) has determined that it is the key component destroyed in the stripping process. The role this reagent plays is still unknown. Attempts to substitute other oxidizing agents has met with failure. This is an important point since the total organic content of the solution could be reduced if an alternative inorganic oxidizing agent could be used. Unfortunately, the electrochemical testing of oxidizing agents has proven ineffective due to facile electron transfer reactions.

During the development of the electroless nickel stripper, attempts were made to quantify how each component affected the stripping rate of electroless nickel. Attempts were then made to identify how each individual component contributed to the overall stripping rate of a formulation. The results indicate that the complexation agent is important to the stripping

rate, but only on the anodic branch of the Tafel plot. This was also true for thiocyanate since its presence also increased the current density on the anodic side. Sodium *m*-nitrobenzenesulfonate was also useful, but only on the cathodic branch of the Tafel plot. With this information, it may be possible to test individual components to determine which ones would make the best ingredients to include in a generic nickel stripping formulation. Unfortunately, it is not certain that the effects of the components will always be additive; therefore, cautious examination of each combination or formulation must still be performed.

The commercial product Metalx B-9 Nickel Stripper was tested using electrochemical techniques to provide a standard for determining how well an electroless nickel stripper was performing. To determine the effects of dilution, it was tested at both full and half-strength. The results indicated that a 50 percent reduction in the strength of the solution would result in a 30 percent reduction in the stripping rate - not quite a one to one ratio.

Since ethylenediamine strippers work exceptionally well for stripping electrolytic nickel, it was decided to test what would happen if ethylenediamine were added to Metalx B-9. The desired result was to improve the electrolytic nickel stripping rate without reducing the effectiveness of the stripper toward electroless nickel deposits. In general, the ethylenediamine based strippers (CLEPO 204) show excellent stripping rates for electrolytic nickel but are totally ineffective toward stripping of electroless nickel deposits. The spiked commercial stripper was tested and yielded the following results. Addition of 5 percent ethylenediamine resulted in a significantly reduced theoretical stripping rate. This was not too surprising since CLEPO 204 is inefficient for removal of electroless nickel plates. However, the addition of only 1 and 2 percent ethylenediamine, yielded an enhancement of the stripping rate.

The data from these electrochemical tests showed small improvements which were difficult to measure. However, since the test results are printed out on a log scale, these small variations could mean an increase of 2 or 3 times the normal stripping rates for nickel. In order to quantify this increase in stripping rate, "jar" tests were performed.

One goal established for this year was to finish formulation of an electroless nickel stripper whose principal ingredients were sodium thiocyanate and sodium *m*-nitrobenzenesulfonate. What remained from last year was to identify an ingredient which would afford protection to the basis metals without sacrificing the nickel stripping rate - not a simple task. A number of corrosion inhibitors were tested and included: calcium hydroxide, sodium carbonate, sodium nitrite, sodium tetraborate (borax), and trisodium phosphate (TSP). Sodium nitrite was tested with no enhancement of basis metal protection. Calcium hydroxide showed exceptional basis metal protection, but it also reduced the nickel stripping rate to an unacceptable level. Sodium phosphate had about the same effect as sodium carbonate, which implies that it is the result of pH rather than the anion; however, neither anion was sufficiently strong to afford protection to the low-alloy steels being tested. The borax was the only ingredient which showed promise since it appeared to inhibit the corrosion of ferrous basis metals (9310), while preserving the high nickel stripping rate even at low concentration (0.10 M). It was tested using jar tests and is discussed in the following section.

Since thiocyanate is known to be a "dangerous" corrosion inhibitor for iron, tests were conducted to determine how its concentration would effect the nickel stripping and basis metal corrosion rates. The term "dangerous" is used to describe a corrosion inhibitor that affords protection to a basis metal when applied in a relatively narrow concentration range. The "danger" arises when the concentration of the inhibitor falls outside the proper range. If the concentration of the inhibitor is too low or too high, corrosion processes are no longer inhibited and may become enhanced. Full-strength and diluted formulations were tested to determine the effects of concentration. The results from this test indicate that reduction in the concentration of ammonium thiocyanate from 1.0 to 0.2 Molar yielded a proportionate drop in the nickel stripping rate from 0.27 to 0.07 millinch per hour, while the ferrous basis metal corrosion rate remained at the same unacceptable rate for both tests.

Another potential electroless nickel stripping solution, based on ammonium citrate and sodium *m*-nitrobenzenesulfonate, was tested. This formulation gave a theoretical stripping rate for nickel that was about the

same as CLEPO 204 and was without any thiocyanate to enhance the stripping rate. When this formulation was tested with ammonium thiocyanate, an increased stripping rate (3 times the unactivated solution), and better basis metal protection was observed. However, a question needed to be resolved as to whether the ammonia generated from the ammonium citrate and thiocyanate was a significant contributor to the stripping rate. If ammonia is an essential component, this formulation would be unacceptable to the Air Force because of the presence of noxious ammonia fumes. Further testing using sodium thiocyanate and sodium citrate proved that ammonia was contributing to the stripping rate but was not exclusively responsible for it. In the absence of ammonia, the solution still stripped nickel, but at a reduced rate. This solution was later tested using laboratory test procedures to determine the stripping rates for electroless nickel plates.

These citric acid based strippers were tested for the effects of added oxidizing agents [hydrogen peroxide, cerium (IV), copper (II), and iron (III)]. The reason the citrate stripping solution was chosen for testing is because the citrate molecule is relatively inert to chemical oxidation. It was hoped that the presence of an oxidizing agent would help remove the electroless nickel plate by oxidizing the phosphorus in the plate and facilitating its removal. The present nickel strippers work by removal of nickel from the plate, but with the high phosphorus nickel plates, the presence of the phosphorus inhibits the stripping reaction. That is why the reverse tact was taken -- removal of the phosphorus first. Unfortunately, the results were inconclusive since electrochemical techniques do not work well in the presence of oxidizing agents. Therefore, the more promising solutions had to be jar tested to determine the stripping rates for electroless nickel plates.

Other electrochemical tests were conducted on a potential stripping solution that contained glycine, sodium carbonate, and sodium *m*-nitrobenzene-sulfonate. This was developed last year and it was later discovered that this was the basic formulation for Metalx B-9 Nickel Stripper. It was encouraging to see that a good electroless nickel stripper could be developed using electrochemical methods, but it was not encouraging to stumble across a potential patent infringement. Where our solution may differ from the

commercial product is in the addition of sodium thiocyanate as an activator, B-9 uses sodium thiosulfate. This solution was also tested for enhancement of the electrolytic nickel stripping rate through addition of ethylenediamine, in a process similar to that previously mentioned for Metalx B-9.

2. Jar Tests

Jar tests were conducted to optimize the generic electrolytic nickel stripper for electroless nickel stripping and yielded very inconsistent data (see test results in Appendix F pages F-3 to F-5). This inconsistency can be attributed to the variability of the coupons used for testing. Since the coupons that were obtained this year were incapable of being stripped, the coupons that were used in last year's tests were collected and refurbished. The results showed that the coupons used to test Niplex 100 stripper last year gave stripping rates 10 times faster than the coupons that were used to test CLEPO 204. This is unequivocally demonstrated by the test results obtained for the 2nd Formulation #3 test which was performed August 6, 1991 (page F-4). These tests yielded stripping rates for electroless nickel of 0.04, 0.04, 0.39, and 0.71 millinch per hour. As can be seen, the last value is almost 20 times that of the first. The wide range of stripping rates obtained using the same formulation is ample evidence to support the conclusion that the sample coupons are not uniform.

In an attempt to get more consistent results, only the coupons that were previously used to test Niplex 100 were used for testing (see the last set of tests presented in Appendix F, pages F-4 and F-5). Unfortunately, even this set of coupons was not uniform enough to allow optimization of the generic nickel stripper to be performed; the variation in the data was still too great. The optimization process must be able to discern small improvements with minor adjustments to the formulation and this was not possible with the coupons available for testing this past year.

Another important test occurred when the commercial formulation, Metalx B-9 Nickel Stripper, was tested for enhanced stripping of electrolytic nickel plates by addition of ethylenediamine to the stripper. The results demonstrated that addition of as little as 1 percent ethylenediamine gave

increased stripping rates for both nickel plate materials (from 0.36 to 0.43 milliinch per hour for Ni-S and from 0.51 to 0.65 for Ni-S, page F-2). This increase in stripping rate was accomplished even though the concentration of Metalx B-9 was 59 gram per liter (0.5 pound per gallon), lower for the solution with ethylenediamine added.

The test with borax as a corrosion inhibitor for the thiocyanate-based stripper showed no improvement in basis metal protection. The corrosion of C4340 coupons was still unacceptable at 0.004 milliinch per hour (see page F-1). This test result was the last attempt to inhibit the basis metal corrosion associated with the thiocyanate-based strippers. After the failure of this test, the thiocyanate-based stripper was no longer investigated.

Jar tests were conducted using the following potential electroless nickel stripper: citric acid, sodium carbonate, sodium *m*-nitrobenzene-sulfonate, and ammonium thiocyanate. The electroless stripping rate was not outstanding - only 0.22 milliinch per hour at 55°C (130°F) for both nickel plates (page F-1). The moderate stripping rates are encouraging since the formulation has not been optimized for pH or composition (relative concentrations of ingredients). These stripping rates are comparable to Metalx B-9 at this test volume; therefore, this stripper may be considered a potential replacement for the B-9 nickel stripper. This solution also afforded basis metal protection to C4340 for twenty-four hours of immersion.

Jar tests were conducted to determine whether oxidizing agents would enhance the stripping rates for electroless nickel strippers since the electrochemical tests proved inconclusive (pgs. F-2 and F-3). It appears that the presence of oxidizing agents increases attack at the surface of the plates, but only at the surface. As far as bulk removal of the nickel plate is concerned, the oxidizing agents appear to passivate the nickel surface and slow down the stripping process. Agents that were unsuccessfully tested included copper (II), cerium (IV), hydrogen peroxide, and iron (III). Some other common oxidizing agents that were not tried included hypochlorite and persulfate. These were not tried since their reduction products, chloride and sulfate, are both known to accelerate attack upon ferrous basis metals.

Another formulation containing glycine, sodium carbonate, sodium *m*-nitrobenzenesulfonate, and ammonium thiocyanate was jar tested. The composition of this stripper is very similar to Metalx B-9 Nickel Stripper (the difference is the addition of thiocyanate). This solution gave a stripping rate for electroless nickel of 0.33 milliinch per hour while the electrolytic nickel was slightly higher at 0.53 (page F-1). All tests were run at 55°C (130°F). The basis metal protection was excellent with no evidence of corrosive effects upon the C4340 test coupons after 24 hours of immersion. Once again, these stripping rates are comparable to Metalx B-9. The inclusion of thiocyanate may enhance the stripping rate, but probably not enough to avoid patent infringement.

More thoughts on electroless nickel stripping. The extreme hardness of the plate may be partially responsible for the difficulty that was encountered when trying to strip it. The electroless nickel plates also contain varying amounts of phosphorus which may be present as the element, as a phosphite, or more likely as nickel phosphide. Unfortunately, there is no known solvent for removing the phosphorus contained in the electroless nickel deposits. The only solutions listed in the Chemical Rubber Company Handbook of Chemistry and Physics (ref. 34) that will dissolve nickel phosphides are nitric and hydrofluoric acids - two chemicals which are not acceptable for use in a generic nickel stripper because of extreme reactivity and toxicity.

One way to remove nickel phosphides may be to oxidize the phosphide to a phosphate. This may be the essential step in removal of electroless nickel coatings. Here a "Catch 22" situation is encountered - since nickel is known to passivate (like iron) in the presence of oxidizing agents. If oxidizing agents are added to the solution, the phosphorus content of the plate will be removed, but the nickel metal will passivate and the stripping process will stop. Conversely, the absence of suitable oxidizing agents will result in nickel removal until a surface coating of phosphorus containing species is present. This push-pull effect of the oxidizing agent will require detailed research and testing in order to find a suitable oxidizing agent which can oxidize the phosphorus content of the plate and not passivate the nickel surface. This may explain why there is an abundance of electrolytic

methods for the stripping of electroless nickel, while immersion stripping is much more rare.

Another concern with electroless nickel stripping is the effects attributable to heat treatment. The effects of heat treatment have not been investigated; however, based upon verbal communication with officials at Tinker AFB, their high phosphorus electroless nickel can be removed with difficulty if it is stripped before heat treatment but is extremely difficult to strip after it has undergone heat treatment. The effects of heat treating of other electroless nickel plate materials used by the Air Force should also be investigated since it is known that the heat treating process should lead to a plate material which is harder to strip.

3. Tests on Alternative Coatings

Samples of several commercially available electroless nickel coatings were obtained and a stripping rate was determined for each stripper currently in use at Kelly AFB (CLEPO 204, Metalx B-9, Ni-plex 100) or projected for future use (the generic formulation). The data is presented in Appendix G while graphs of the data can be found in Appendix H. This work was performed in support of our host base in San Antonio since they were considering implementation of a commercial electroless nickel process to replace the generic process they currently use at Kelly AFB. The interest was in determining if any of the strippers which have been implemented, or forecast for implementation, would be able to strip these new coatings.

The results of this testing showed that one of the commercial electroless nickel plating processes (Enthone-OMI, Inc. Enplate Ni-425) yielded a high phosphorus nickel coating that was unable to be stripped by any of the solutions we tested. This included Metalx B-9, Ni-plex 100 (a B-9 look-alike), CLEPO 204, and the generic stripper. Even the C-106 cyanide immersion process was tried without success (see graphs on pages H-10 and H-11). The other plate being considered for implementation (Witco Chem. Corp. Niklad* 797) was stripped by all of the nickel strippers. In fact, the generic stripper out-performed all others. This comparison is not entirely fair since the commercial strippers were being used in the plating shop at the

time of testing and some had significantly deteriorated from the time of initial make-up. The nickel-boron coatings were also tested and yielded excellent stripping rates for those strippers designed to remove electrolytic nickel deposits (CLEPO 204 and generic).

D. BIOLOGICAL TREATMENT OF NONCYANIDE METAL STRIPPER WASTES

Stage I and Stage II biodegradation and compatibility experiments were conducted in the Laboratory Facility at the Kelly AFB IWTP between June and August of 1991. The bench-scale continuous-flow bioreactors gave results which indicate the preferred methodology to use for treatment of waste solutions containing ethylenediamine. Several problems were encountered during testing which may be of interest to Air Force officials. One problem concerned the wet-chemistry (HACH) methods which were initially intended for analysis of nitrate, nitrite, ammonia, phosphate, and sulfate. These methods had to be replaced with analysis by Ion Chromatography due to interference from a number of contaminants (including iron and other organics) in the IWTP wastewater. If these methods (some of which are widely used throughout the wastewater treatment industry) are used to obtain effluent or influent quality data, the results may be in error due to interference from the contaminants in the wastewater matrix. It cannot be determined whether this may have contributed to the technical difficulties experienced in obtaining valid Kjeldahl nitrogen data. The Kjeldahl nitrogen test uses the same HACH method for detection of ammonia in a sample which has been digested by the Kjeldahl method. Other concerns will be addressed in the following sections.

1. Stage I Biodegradability Tests Using Spent CLEPO 204

The ICP data (not included) showed that 150 ppm nickel still remained in the spent CLEPO 204 sample after metals precipitation and filtration. This may be the result of small nickel sulfide particles passing through the filter ($0.45 \mu\text{m}$) material. Because there was not a method available for further removal of nickel, the CLEPO 204 stock solution was diluted ten-fold with Nano-pure water and used for a carbon source stock solution. The resulting nickel concentration was 0.3 ppm in 100 mL of the EPA Minimal Media used for

the shake-flask experiments (see Appendix 0 of the NCYS Program Phase III Final Report, ref. 3, for EPA Minimal Media components).

It was interesting to find that even after metals precipitation and filtration, 150 ppm nickel was still present in the spent CLEPO 204 sample. Several different ratios of ingredients were tried (thinking that possibly the formula was incorrect), and several different filtration methods (even going as small as 0.2 μm), but a solution no lower than 150 ppm nickel could be obtained. At this point the question arose "How does this work on an industrial scale when it will not work in the lab?". The possible implication is that the sulfide precipitation method currently used at the Kelly AFB IWTP is an inefficient heavy metals precipitation method for treating spent CLEPO 204 wastes. If this is true, then some problems may arise when ethylenediamine containing wastes are treated for heavy metals removal. The heavy metals which pass through the precipitation process will end up in the activated-sludge basin. The toxic effects of heavy metals could cause activated-sludge upset and system failure. This issue remains unresolved, but is tied to further discussions in section G (RED COLORED WATER).

The results of the HPLC studies from the shake-flask experiments are detailed in Table 4 below. All three flasks containing CLEPO 204 and activated-sludge microorganisms showed an increase in turbidity (biomass) and a small decrease in *m*-nitrobenzoate concentration. However, the orange-yellow discoloration of the broth was not affected. This is probably an indication that some carbon sources in the spent stripper were degraded (such as ethylenediamine and *m*-nitrobenzoate) but those components responsible for the orange-yellow discoloration were not degraded in the time frame the experiments were conducted. It should also be noted that Flask #2 gave the highest percentage of *m*-nitrobenzoate removal at 19.7 percent. This is a rather poor performance and leads one to expect lower efficiency with the bench-scale continuous-flow bioreactor. Another possibility is that the initial ethylenediamine and *m*-nitrobenzoate concentration was too high, leading to inhibition rather than biodegradation. In any case, the results from the bioreactor studies were favorable and strongly support the method of biological treatment for ethylenediamine containing wastes.

TABLE 4. SHAKE-FLASK TEST RESULTS USING CLEPO 204.

| <u>Flask</u> | <u>m-Nitrobenzoate (ppm)</u> | <u>Time</u> |
|--------------|------------------------------|-------------|
| #1 | 124.0 | 0 Hrs. |
| | 120.6 | 24 |
| | 108.7 | 48 |
| #2 | 158.2 | 0 |
| | 129.8 | 24 |
| | 127.1 | 48 |
| #3 | 181.3 | 0 |
| | 173.0 | 24 |
| | 164.8 | 48 |
| #4 CONTROL | 185.0 | 0 |
| | 185.0 | 24 |
| | 185.0 | 48 |

2. Stage II Bench-Scale Continuous-Flow Bioreactor Experiments

a. Ethylenediamine Removal at pH 7.0

The pH 7.0 experiments using ethylenediamine as a substrate took place in column #1. The data from column #3 was used as the pH 7.0 control. The data and graphs mentioned in this section pertain to columns #1 and the control column #3. The data can be found in Appendix I, and the graphs are found in Appendix J.

For the first 192 hours of experiment run-time an influent flow rate of 14 mL per minute (5.3 hour contact time) was used for all of the bioreactors. This retention time is representative of the contact time used at the IWTP in the central activated-sludge basin, even slightly longer (the IWTP has been averaging 4.5 hour activated-sludge contact times). The graph on page J-1 shows that after 168 hours of ethylenediamine exposure (7 days, and 31.7 turnover periods) using a 5.3 hour contact time, very poor ethylenediamine removal resulted. The graph on page J-2 shows the first order linear-regression line through the 0 to 192 hours influent/effluent ethylenediamine

data. The first order linear-regression line represents a general data trend. The graph demonstrates that there existed a proportional relationship between influent and effluent ethylenediamine concentration for a 5.3 hour contact time (i.e., as the influent ethylenediamine concentration increased, so did the effluent concentration). This indicates very little or no ethylenediamine removal.

The graphs on pages J-5 and J-6 show the influent and effluent TOC for the 5.3 hour contact time. The trend plot of the TOC data (page J-6) shows that as the influent TOC increased (slightly), the effluent TOC also increased (slightly). This evidence is further demonstrated in the influent and effluent COD graphs found on pages J-9 and J-10. The influent and effluent COD trend plot on page J-10 shows a very poor influent and effluent correlation.

If significant biodegradation was taking place then a flat effluent line should have been seen, not increasing lines as are seen in the TOC, COD, and ethylenediamine trend graphs.

Finally, the percentage removal of ethylenediamine for the 5.3 hour contact time is demonstrated by the graph on page J-15. The initial percentage is high (100 percent at 24 hours) because the percentage removal is calculated from the amount of ethylenediamine in the effluent versus the influent. It can be seen from the graph on page J-1 that the influent was spiked with ethylenediamine at 24 hours, and ethylenediamine in the effluent was not detectable until 32 hours. As the column equilibrated, the percentage removal dropped off rapidly. A better representation of the data can be found between hours 54 and 192 (see graph page J-15). The percentage removal averages out at 8.8 percent. This is very poor removal but is slightly better than the percentage ethylenediamine removal for the pH 8.5 experiment (average of 1.5 percent between 48 and 192 hours).

Why such poor efficiency? Several possible answers existed for this finding. The first possibility was that biodegradation was either not occurring, or was inhibited. The second possibility was that acclimation had

occurred and biodegradation was occurring, but only on a low scale. The arguments which resolved this issue were as follows.

Since the ability to biodegrade ethylenediamine was shown to exist previously, then ethylenediamine biodegradation should have been recordable within 72 hours after introduction of ethylenediamine into the influent. Previously conducted shake-flask studies showed us that within 72 hours, a microbial population from the Kelly AFB IWTP activated-sludge culture acclimated, proliferated, and degraded all of the ethylenediamine present in the flask. After isolating several strains from this mixed culture, the isolated strains could utilize ethylenediamine as their only source of carbon and energy. The utilization of ethylenediamine resulted in an increase in biomass, an increase in culture media ammonia, and a decrease in the ethylenediamine concentration. These previous studies also showed that 150 ppm ethylenediamine could be removed within 18 hours (see NCYS Phase III Final Report, ref. 3).

Even though the activated-sludge population had undergone change since the shake-flask tests were conducted, it was still believed that biodegradation (acclimation of the culture, proliferation of the population, and removal of the substrate) should have been noticed within 72 hours. But the influent/effluent TOC, COD, and ethylenediamine data showed us that very little ethylenediamine was being removed. This may be attributed to either a very low level of biodegradation, inhibition of biodegradation, an excessive flow rate, or a combination of these problems. If biodegradation was occurring, but on a very low scale, then increasing the fluid retention time would result in a decrease of effluent ethylenediamine until it was gone. If inhibition was occurring, then an increase in fluid retention time would result in a very slow removal rate, or no removal at all.

The more likely possibility was that the influent substrate flow rate exceeded the rate of substrate removal by the biomass. In this case acclimation had occurred and biodegradation was taking place, but the influent flow rate was so fast that the microorganisms did not have a significant effect on the substrate concentration. If this were the case, then why were biodegradation by-products undetectable? This is probably because the flow

rate was so fast, and the removal rate so low (8.8 percent), that any evidence for biodegradation was being diluted out. The biomass health and density indicators (MLSS, SVI, and SOUR) also indicated that biological activity was low and the biomass concentration was lean. At the time, these were the same conditions being experienced at the IWTP. It was later found out that this is somewhat typical of the Kelly AFB IWTP operations.

Table 5 demonstrates the biomass health indicators for the two bioreactors used in testing. The MLSS data for column #1, between time zero and 192 hours, shows that the activated-sludge suspended solids concentration was as high as 4,280 ppm, as low as 2,760 ppm, and averaged 3,200 ppm. It should be noted that a manual sludge recycle system was employed. Therefore, the value of the MLSS is a reflection of the time elapsed since the last recycle was performed. The high and low values for MLSS should be reviewed with this in mind; however, the average value probably offers the best representation of the MLSS data. The SVI ranged from a high of 50.5 mL per gram, to a low of 25.2 mL per gram, and averaged 35.8 mL per gram. The respiration rate ranged from a high of 16.2 mg oxygen consumed per mL per hour, to a low of 3.0 mg oxygen consumed per mL per hour, and averaged 8.4 mg oxygen consumed per mL per hour. The control column #3 data for time zero to 192 hours shows us that the MLSS of the control ranged from a high of 3,200 ppm, to a low of 2,120 ppm, and averaged 2,517 ppm. The SVI for control column #3 ranged from a high of 50.2 mL per gram, to a low of 29.4 mL per gram, and averaged 39.4 mL per gram. The respiration rate ranged from a high of 14.4 mg oxygen consumed per mL per hour, to a low of 1.8 mg oxygen consumed per mL per hour, and averaged 8.0 mg oxygen consumed per mL per hour.

It can be seen from the data in Table 5 that there is very little difference between the two bioreactors (#1 and #3) during the 5.3 hour contact time experiment. This could indicate that ethylenediamine was not causing any detrimental effects to the biomass. Another possibility is that the IWTP process water may have contained a chemical which was causing inhibition during the 5.3 hour contact time experiment. Yet, if this were due to elevated levels of an inhibiting organic compound, then the TOC and COD of the influent should have detected this. The influent TOC data for the control column #3 from 0 to 192 hours ranges from a high of 92.4 ppm, to a low of 45.6

TABLE 5. RESPONSE TO 5.3 HOUR CONTACT TIME.

| | MLSS | | SVI | | SOUR | |
|--------------------|-----------|------|-------|------|------|------|
| | #1 | #3 | #1 | #3 | #1 | #3 |
| Highest | 4280 | 3200 | 50.5 | 50.2 | 16.2 | 14.4 |
| Lowest | 2760 | 2120 | 25.2 | 29.4 | 3.0 | 1.8 |
| Average | 3198 | 2517 | 35.8 | 39.4 | 8.4 | 8.0 |
| Accepted Standards | 4000-6000 | | < 100 | | 25.0 | |

MLSS units are ppm.

SVI units are mL per gram.

SOUR units are mg oxygen per mL per hour.

ppm (discounting the value of zero at 72 hours), and averaged 67.6 ppm. The influent COD value ranged from a high of 42 ppm (discounting the value of zero at 72 hours), to a low of 7 ppm, and averaged 28.7 ppm. These TOC and COD values, if anything, point to carbon limiting conditions. This rules out the possibility of an organic inhibitor, but indicates nothing about heavy metal or other inorganic inhibition. It cannot be determined from the data if this is the case, but it is known that once the fluid retention time was changed, a dramatic increase in biological activity occurred.

Because ethylenediamine removal was very poor up to 192 hours of exposure, one of many options could have been elected to be exercised. Increasing the contact time was the first logical choice. It was reasoned that if the activated-sludge could not acclimate and demonstrate appreciable (99 percent) biodegradation within 72 hours, then it was not feasible for the IWTP to pursue treatment of this chemical. The logic is that the IWTP does not have more than 72 hours in which it can run on recycle or shut down activities to give the activated-sludge time to acclimate. A period greater than 72 hours was felt to be too long and would compromise the operations at the Kelly AFB IWTP. It was also believed that biological activity was occurring but on a scale too small to detect with the available analytical instrumentation. Lastly, it was believed that a contact time of 5.3 hours was insufficient and resulted in a very poor 8.8 percent ethylenediamine removal efficiency.

At 192 hours experiment run-time, the influent flow rate was decreased to 9 mL per minute (8.3 hours contact time). Within 24 hours (2.8 turnover periods) ethylenediamine could not be detected in the effluent. From 192 hours to 912 hours the influent flow rate was held at 9 mL per minute and the influent ethylenediamine concentration was increased stepwise up to 700 ppm. Even at a concentration as high as 700 ppm ethylenediamine, the activated-sludge culture performed very well and no ethylenediamine could be detected in the effluent. Results approaching these using a 5.3 hour contact time could not be obtained.

The graphs on pages J-1 and J-4 show the effects of changing the contact time from 5.3 hours to 8.3 hours. These graphs demonstrate that at a contact time of 8.3 hours, 100 percent of the influent ethylenediamine was removed. The trend plot on page J-3 demonstrates that as the influent ethylenediamine trend increased, the effluent ethylenediamine trend remained relatively flat at zero (with minor spikes).

The influent and effluent TOC data for the 8.3 hour contact time can be found in the graphs on pages J-7 and J-8. The trend plot on page J-8 demonstrates that as the influent TOC increased, the effluent TOC only slightly increased, but remained relatively flat. The 8.3 hour influent and effluent COD plots are found on pages J-11 and J-12. The trend plot on J-12 demonstrates that as the influent COD increased, the effluent COD remained flat. During the highest ethylenediamine concentration period (894 to 918 hours run-time), the influent TOC for column #1 averaged 246.6 ppm, while the effluent TOC averaged 110.9 ppm. This is a 55 percentage removal of the influent TOC. The influent COD averaged 693 ppm, and the effluent COD averaged 105 ppm. This is an 84.8 percentage removal of the influent COD. Both the TOC and COD removal efficiencies are very high compared to the control column #3 (28.3 percent TOC removal, and 24 percent COD removal) for this period. The efficiency probably could have been pushed even higher if the contact time would have been increased. The efficiency could also have been enhanced by modifying the clarifier design (to a larger capacity beaker). The bench-scale bioreactors tend to loose solids over several days of operation and required weekly inputs of activated-sludge from the IWTP.

However, this was only a minor flaw inherent in the design and can be corrected in future tests.

The MLSS, SVI, and SOUR data from column #1 and #3, for the time period immediately following the flow rate change (216 to 318 hours), is presented in Table 6. The MLSS for column #1 was as high as 8,430 ppm, as low as 2,070 ppm, and averaged 5,659 ppm. The SVI ranged from a high of 62.8 mL per gram, to a low of 33.2 mL per gram, and averaged 41.3 mL per gram. The SOUR drastically came alive ranging from a high of 29.4 mg oxygen consumed per mL per hour, to a low of only 12.0 mg oxygen consumed per mL per hour, and averaged a healthy 20.1 mg oxygen consumed per mL per hour. The MLSS for the control column ranged from a high of 6,920 ppm, to a low of 1,600 ppm, and averaged 4,900 ppm. The SVI ranged from a high of 81.2 mL per gram, to a low of 39.0 mL per gram, and averaged 45.0 mL per gram. The SOUR ranged from a high of 23.4 mg oxygen consumed per mL per hour, to a low of 8.4 mg oxygen consumed per mL per hour, and averaged 14.3 mg oxygen consumed per mL per hour. Table 6 demonstrates the 8.3 hour contact time response for these two bioreactors.

The response in column #1 at the 8.3 hour contact time is significantly different than the 5.3 hour response. Ethylenediamine is removed from the effluent, the biomass health and density indicators showed a marked increase, and degradation by-products appeared in the effluent.

The next question which was asked was "Does it really take 192 (168 plus 24) hours to acclimate?". This question is addressed in Section (d), below, as pertains to data obtained using spent CLEPO 204 stripper.

b. Effluent Ammonia from Ethylenediamine Degradation

The graph on page J-13 demonstrates that when inefficient ethylenediamine degradation occurred during the 5.3 hour contact period, no effluent ammonia (a degradation by-product) could be detected. However, when the contact time was increased to 8.3 hours, the effluent ammonia concentration shot up rapidly in conjunction with the disappearance of ethylenediamine. The graph on page J-14 shows that the effluent ammonia could

TABLE 6. RESPONSE TO 8.3 HOUR CONTACT TIME.

| | MLSS | | SVI | | SOUR | |
|--------------------|-----------|------|---------------|------|------|------|
| | #1 | #3 | #1 | #3 | #1 | #3 |
| Highest | 8430 | 6920 | 62.8 | 81.2 | 29.4 | 23.4 |
| Lowest | 2070 | 1600 | 33.2 | 39.0 | 12.0 | 8.4 |
| Average | 5659 | 4900 | 41.3 | 45.0 | 20.1 | 14.3 |
| Accepted Standards | 4000-6000 | | less than 100 | | 25.0 | |

MLSS units are ppm.

SVI units are mL per gram.

SOUR units are mg oxygen per mL per hour.

be detected only while the bioreactor was run using an 8.3 hour contact period. In comparing the effluent ammonia graph on page J-14, and the influent/effluent ethylenediamine graph on page J-4, it can be seen that as the influent ethylenediamine concentration increased, the effluent ammonia increased as well. It is interesting to note that the effluent ammonia concentration reached as high as 147 ppm in this reactor.

The increase in effluent ammonia poses a potential problem for treating ethylenediamine in the full-scale on-line IWTP facility. Because the Kelly AFB IWTP design does not include a treatment method for excessive effluent ammonia and nitrate, the effluent concentrations could (and probably will) exceed NPDES limits of 10 ppm. By calculation, roughly 30 ppm influent ethylenediamine resulted in 10 ppm effluent ammonia. This problem may not be restricted to only ethylenediamine solutions. Other chemicals, which are used or targeted for use in upstream processing facilities, also contain organic nitrogen atoms which may contribute to excessive effluent nitrate and ammonia. For example, the metal stripping product Metalx B-9 contains an amino acid (glycine) which has an organic nitrogen atom. Nitroaromatic corrosion inhibitors contain organic nitrogen. There are also numerous examples of inorganic sources of nitrogen. Some metal strippers use nitric acid. Nitric acid will undeniably contribute to the effluent nitrate level. Also included in this list are those inorganic chemicals which contain nitrate, nitrite, and ammonia salts. All of these will contribute to the influent and effluent

nitrate load. Evidence that this may already occur can be seen in the control column #3 influent data. Influent nitrate levels were as high as 19.2 ppm. Effluent nitrate levels were as high as 11.5 ppm. Influent nitrite levels ranged as high as 14.9 ppm, and effluent nitrite concentrations reached as high as 9.1 ppm. During one 24 hour period, the combined effluent nitrate and nitrite concentration was 20.5 ppm. This occurrence, when put in light of the fact that the Kelly AFB IWTP treatment design does not incorporate any method of denitrification (other than what might occur in the aeration basins and the clarifiers during normal operations), indicates that problems with excessive effluent nitrogen levels may arise as the waste stream becomes more complex. The point to be made here is that any chemical which is targeted for implementation into upstream facilities should be tested to determine how it will affect the waste stream both before and after biodegradation.

The benefit of ammonia production is that ammonia is a very readily utilized form of nitrogen, and that nitrogen in general is an important nutrient for biomass protein assimilation. It is possible that if treated in a small-scale facility (such as the pilot plant), which feeds effluent into the main IWTP, the excess ammonia can be utilized by the activated-sludge culture in the central IWTP aeration basins. This way the excess ammonia could become a nutrient assimilated into the biomass and not pose a problem with discharge.

c. Ethylenediamine Removal at pH 8.5

The experiments at pH 8.5, using ethylenediamine as a substrate, were run in column #6 while column #4 was used as the control. The data can be found in Appendix I, while the graphs are presented in Appendix J.

The graph on page J-63 demonstrates that at a higher pH window ethylenediamine removal still occurs but is more efficient at an 8.3 hour contact time. This is similar to the response seen at pH 7.0. The only noticeable difference is that the lag period for ethylenediamine removal is longer at the higher pH. When the influent flow rate was changed at 192 hours, it took until 408 hours experiment run-time to achieve 100 percent removal of ethylenediamine from the effluent. Compared to the 24 hour

response seen at pH 7.0, this is a much slower response. This response to pH was expected since it follows the classical effects that pH has upon biological activity. The graph on page J-64 also demonstrates ethylenediamine removal at pH 8.5. It can be seen from this graph that as the influent ethylenediamine concentration increased, the effluent ethylenediamine remained undetectable.

An interesting occurrence can be found on the graph on page J-64. The graph demonstrates that at 696 hours a large ethylenediamine influent spike was experienced. The effluent ethylenediamine also shows a spike, which is slowly removed within 30 hours. This simply demonstrates that even at an 8.3 hour contact time large carbon spikes take time to be removed.

It should also be noted that the effluent ammonia concentrations reached as high as 147 ppm in this reactor (see page J-68). This response is similar to that observed at pH 7.0.

d. Spent CLEPO 204 Components Removal

The experiment at pH 7.0, using spent CLEPO 204 (containing ethylenediamine and *m*-nitrobenzoate) as a substrate, was conducted in column #2. Data obtained from column #3 was used as the pH 7.0 control. Data and graphs can be found in Appendices I and J, respectively.

Spent CLEPO 204 components were not effectively removed until the contact time was increased to 8.3 hours. The graphs on pages J-16 and J-17 demonstrate the ethylenediamine removal response for 5.3 and 8.3 hour contact times. The graphs on pages J-31 and J-32 demonstrate the *m*-nitrobenzoate removal response for 5.3 and 8.3 hour contact times. It can also be seen from the graphs on pages J-17 and J-32 that as the ethylenediamine and *m*-nitrobenzoate concentrations increased in the effluent, the activated-sludge culture continued to degrade these two carbon sources.

Trends for the TOC and COD data, at 8.3 hour contact periods, are found in the graphs on pages J-25 and J-29. These demonstrate that as the influent TOC and COD increased, the effluent TOC showed a slight negative

slope, while the effluent COD remained flat with no increase. This is an excellent response.

The concentration of ethylenediamine used for the column #2 experiment was less than that used in the column #1 test (157 versus 700 ppm ethylenediamine). The purpose for this was to maintain carbon limiting conditions in the spent CLEPO 204 column. Carbon limiting conditions would place a higher selective pressure on the microorganisms in the column, and promote utilization of the "red" component as a carbon source. This attempt was unsuccessful, as explained in the following section.

As mentioned earlier in section (a), data obtained from ethylenediamine degradation in this column (#2) showed us that the acclimation time response to ethylenediamine was not as long as 192 hours. Introduction of spent CLEPO 204 (32.7 ppm ethylenediamine) into column #2 did not occur until 72 hours experiment run-time, 48 hours after column #1 was spiked with ethylenediamine. At 222 hours (30 hours after the influent flow rate change) ethylenediamine was not detectable in the effluent of column #2. After 120 hours exposure time (5 days, 22.6 turnover periods) the influent flow rate was changed and ethylenediamine removal occurred within 30 hours in column #2. This is a total of 150 hours for column #2 (120 hours plus 30 hours). If the acclimation time had been 192 hours, then ethylenediamine would not have been removed from the effluent of column #2 until 264 hours. However, this was not the case. This response led to the belief that acclimation to ethylenediamine probably occurred within 72 hours after introduction of that chemical, and that biodegradation was occurring during the 5.3 hour contact time experiment, but that the influent flow rate was too excessive and thus resulted in poor treatment.

The pH 8.5 experiment using spent CLEPO 204 as the substrate was conducted in column #5. Data collected from column #4 was used as the control for the experiments at pH 8.5.

The graph on page J-44 demonstrates the 5.3 and 8.3 hour contact time response of ethylenediamine removal at pH 8.5. The graph on page J-58 demonstrates the 5.3 and 8.3 hour contact time response of *m*-nitrobenzoate

removal at pH 8.5. As seen from these two graphs, both ethylenediamine and *m*-nitrobenzoate degradation follow a similar pattern as seen in the pH 7.0 experiment. The graphs on pages J-45 and J-59 demonstrate that as the influent concentration of CLEPO 204 increased, the effluent ethylenediamine and *m*-nitrobenzoate concentrations remain at zero.

The graphs on pages J-56, J-57, and J-62 show the increase in effluent ammonia and nitrate concentrations as biodegradation of ethylenediamine and *m*-nitrobenzoate occurs. This response is similar to that seen in the pH 7.0 experiment.

e. Attempted "Red Water" Components Removal from Spent CLEPO 204

Even with the increased contact time of 8.3 hours (up from 5.3 hours), the "red" discoloration was not removed. As the influent CLEPO 204 concentration increased, the effluent became more highly colored. However, the two major carbon sources (ethylenediamine and *m*-nitrobenzoate) were removed as discussed previously. What is worth noting is that HPLC assays of the spent CLEPO 204 solution showed 14 different unknown peaks (16 peaks total, two were attributed to ethylenediamine and *m*-nitrobenzoate). The effluent which was collected from the bioreactors showed only one peak at 2.81 minutes retention time. This peak has the same retention time as one of the 14 unknown peaks. The effluent peak area also increased as the influent spent CLEPO 204 concentration increased. This could be the unknown "red water" component - only time and further experimentation can tell for sure.

After this experiment had been completed, the influent flow rate was decreased further until the contact time was 12 hours. The bioreactor was then run at a 12 hour retention time for 1 week. Even at a 12 hour retention time the red color was not removed. It appears that the physical/chemical conditions and culture population could not remove the "red" constituent.

It is not known which component is responsible for the "red water" problem. This will need further investigation. However, it remains a strong possibility that either a chemical or biological treatment for this component can be developed.

f. Effluent Ammonia and Nitrate from Ethylenediamine and *m*-Nitrobenzoate Degradation

As demonstrated in the graphs on pages J-20, J-21, and J-33 effluent ammonia and nitrate increased as a result of ethylenediamine and *m*-nitrobenzoate removal. The effluent nitrate concentration was elevated as high as 20 ppm in reactor #2, compared to 11 ppm in the control column. Effluent nitrate poses a greater problem than does effluent ammonia. This is because nitrate is not as readily utilized as ammonia by the majority of activated-sludge microorganisms. There are microorganisms that can convert and utilize nitrate, but it is not known if this population can be established and maintained at the Kelly AFB IWTP. This is also compounded by the fact that denitrification methods are not an integral part of the existing Kelly AFB IWTP design. No denitrification activity was observed in the clarifiers during experimentation.

3. Microbial Assays

After it had been established that each column was degrading either ethylenediamine, or spent CLEPO 204 (ethylenediamine and *m*-nitrobenzoate), serial dilutions were made from aliquots of the activated-sludge in each column. The list of microorganisms presented in Table 7 demonstrates the variety that exists in the activated-sludge. Of importance is the significantly different population found in the control columns as compared to those columns which received ethylenediamine or CLEPO 204. *Arthrobacter ureafaciens*, *Curtobacterium citreum*, *Bacillus subtilis*, *Bacillus licheniformis*, and *Aurobacterium saperdae* seem to be the predominate species in the bioreactors which received ethylenediamine, or ethylenediamine and *m*-nitrobenzoate as substrates. The control columns contained mostly *Pseudomonas cichorii*. It should be pointed out that the control columns contained only 10^5 microorganisms per mL, and had a very low concentration of known floc forming microorganisms. The columns which were receiving higher influent carbon concentrations (e.g., columns #1 and #6 at 700 ppm ethylenediamine), had cell counts of 10^8 viable cells per mL. This is a 1000 fold increase over 10^5 cells per mL found in the control columns.

TABLE 7. MICROBIAL ASSAY RESULTS.

| <u>Column #</u> | <u>Substrate</u> | <u>Strain</u> | <u>Frequency</u> |
|-----------------|--|---|--|
| 1 | Ethylenediamine pH 7.0 | <i>Arthrobacter ureafaciens</i> <i>Bacillus licheniformis</i> <i>Bacillus sp.</i> <i>Curtobacterium citreum</i> <i>Agrobacterium tumefaciens</i> <i>Cellulomonas fimi</i> <i>Micrococcus luteus</i> <i>Acinetobacter baumanii</i> | 10 ⁸ 10 ⁸ 10 ⁸ 10 ⁸ 10 ⁸ 10 ⁷ 10 ⁶ 10 ⁵ |
| 6 | Ethylenediamine pH 8.5 | <i>Auropacterium saperdae</i> <i>Bacillus subtilis</i> <i>Bacillus laterosporus</i> <i>Cellulomonas fimi</i> <i>Arthrobacter nicotianae</i> <i>Flavobacterium mizutaii</i> <i>Bacillus licheniformis</i> <i>Acinetobacter junii</i> <i>Comamonas testosteroni</i> <i>Agrobacterium tumefaciens</i> <i>Pseudomonas stutzeri</i> <i>Arthrobacter ureafaciens</i> | 10 ⁸ 10 ⁸ 10 ⁷ 10 ⁷ 10 ⁶ 10 ⁶ 10 ⁵ 10 ⁵ 10 ⁵ 10 ⁵ 10 ⁵ 10 ⁵ |
| 2 | Spent CLEPO 204 (ethylenediamine) (<i>m</i> -nitrobenzoate) pH 7.0 | <i>Curtobacterium citreum</i> <i>Aeromonas caviae</i> <i>Comamonas acidovorans</i> <i>Pseudomonas sp.</i> <i>Pseudomonas cichorii</i> <i>Pseudomonas facilis</i> <i>Arthrobacter ureafaciens</i> | 10 ⁶ 10 ⁶ 10 ⁶ 10 ⁵ 10 ⁵ 10 ⁵ 10 ⁵ |
| 5 | Spent CLEPO 204 pH 8.5 | <i>Bacillus licheniformis</i> <i>Arthrobacter ureafaciens</i> <i>Citrobacter freundii</i> <i>Cellulomonas fimi</i> <i>Acinetobacter junii</i> <i>Agrobacterium tumefaciens</i> | 10 ⁷ 10 ⁶ 10 ⁶ 10 ⁶ 10 ⁵ 10 ⁵ |
| 3 | Control pH 7.0 | <i>Microbacterium sp.</i> <i>Pseudomonas cichorii</i> | 10 ⁵ 10 ⁵ |
| 4 | Control pH 8.5 | <i>Pseudomonas mendocina</i> <i>Pseudomonas cichorii</i> | 10 ⁵ 10 ⁵ |

E. COLORED WASTEWATER

The species responsible for the red coloration observed in the wastewater from metal finishing processes was unofficially investigated during the last reporting period. This past year, the budget did not allow for investigation into this area; however, casual investigations in the library have yielded a number of potential sources for the red coloration. These potential sources, as identified from literature precedents, include nickel complexes in solution, formation of hydropolysulfides from reaction of ethylenediamine with the sulfur found in electrolytic nickel plates, and formation of diazo dyes from reduction of the nitroaromatic chemicals used for corrosion inhibition in numerous stripping and cleaning solutions.

When nickel is dissolved in water, it usually forms green solutions. This is because the nickel in solution is almost exclusively bonded to water molecules. When amines are present, they displace the water and coordinate preferentially with the nickel to form highly colored species that are usually blue or purple (ref. 35). These amine compounds, in the presence of other colored species, could be partly responsible for the intense reddish-brown coloration observed in the used nickel stripping solutions and deserves attention. If these nickel species are responsible for coloration of the used stripping solutions, metals precipitation should remove the color.

Another component in the formulation that may contribute to the development of a red coloration is ethylenediamine. This is based upon an article contained in a book on the "Reactions of Sulfur with Organic Compounds" (ref. 33). The article states that the reaction of ethylenediamine with elemental sulfur at 50°C can lead to formation of hydropolysulfides which are an orange-red color.

The last process potentially responsible for formation of the colored solution is also the most likely. This process forms colored species from the reduction of the aromatic nitro compounds found in many of the metal finishing solutions. These aromatic nitro compounds are added to prevent corrosion of ferrous basis metals and to aid in nickel stripping. The chemical reduction of the nitro group results in the formation of N=N bonded aromatic diazo

compounds (ref. 36). These aromatic diazo compounds are characteristically highly colored (diazo dyes) and the color is pH sensitive (ref. 34). The red coloration resulting from reaction of sodium *m*-nitrobenzenesulfonate may be due to the formation of 4,4'-azobenzenedisulfonic acid (CAS# [2779-21-7]) or its dianion (CAS# [3646-56-8]).

The production of diazo compounds by reduction of aromatic nitro groups is well precedented (refs. 36,37). This reaction has been known since the turn of the century when research on this family of dyes was prevalent. The chemistry of these compounds has been thoroughly investigated and the means for destroying the coloration has also been determined. In most cases, the reverse reaction was more thoroughly investigated since the means for preserving the chemical species in order to retain the coloration was important. This research has lead to the discovery that chemical reduction of the diazo (N=N) linkage to a hydrazine (HN-NH) or full N-N bond cleavage to amines (NH₂) will result in quenching of the chromophore and loss of coloration. Sodium dithionite (sodium hydrosulfite) has been used to clean and decolorize dye-vats since it will chemically reduce the diazo linkage and destroy the color (ref. 36). Treatment with this chemical (or another suitable reducing agent) may be all that is needed to destroy the red coloration. It may also be that the standard treatment techniques used to precipitate the nickel from solution may be sufficiently reducing to destroy the species responsible for the coloration in the metal finishing wastewaters (refs. 36,38-40). If this is the case, then the concern that the red coloration will prevent discharge of the treated wastewater will be eliminated. The effectiveness of any treatment process to destroy the "red water" will need to undergo further investigation before any recommendation can be made.

SECTION V CONCLUSIONS

A. IMPLEMENTATION OF COMMERCIAL STRIPPERS

1. Metalx, Inc. B-9 Nickel Stripper

This stripper has yielded higher stripping rates for electroless nickel deposits than any other alkaline stripper we have tested. Corrosion testing was positive with only one batch of test coupons showing adverse effects. This one test result may have been caused by aircraft parts inadvertently placed on top of the test coupons. Over 566 aircraft parts were processed using this stripper and most were stripped within four to eight hours of immersion. Since this formulation contains sodium carbonate buffer (as well as glycine and sodium *m*-nitrobenzenesulfonate), the pH of the solution was remarkably constant and only varied by 0.3 pH unit over the implementation test period of four months. The stability of the pH was also partly responsible for the excellent basis metal protection obtained for all aircraft parts processed using this stripper.

B-9 Nickel Stripper has demonstrated an excellent capacity for regeneration; however, it also showed sensitivity to thermal decomposition. Since it contains an amino acid, it has excellent inherent biodegradability properties. It may be that the biodegradable components of this stripper are also the ones that show thermal instability. Therefore, it must be decided if the extra precautions needed to keep the bath from overheating are worth the enhanced biodegradability offered by this stripping product. When the stripper is kept within the temperature limits specified by the manufacturer and recommended by EG&G, as demonstrated by the second batch tested at Kelly AFB, this bath has shown very good stability for plate metal stripping and basis metal protection.

2. McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper

Rostrip 999-SP has proven itself to be an acceptable replacement for the Air Force's C-101 electrolytic cyanide stripper in applications requiring silver stripping. It is an electrolytic stripper that contains sodium nitrate, sodium nitrite, and sodium hydroxide. It efficiently stripped silver at over 8 milliinch per hour and afforded reasonable protection to low-alloy and stainless steel basis metals. However, one must exercise extreme caution with Haynes 188 or Inconel 718 basis metals since these alloys underwent extensive attack. If Haynes and Inconel parts are to be stripped, the nitric acid immersion stripper can be used.

Rostrip 999-SP was used to strip a total of 144 aircraft parts. Most of these parts were completely stripped within 15 to 30 minutes. There was no corrosion of the basis metals within this time-frame and the only detrimental side effect was that some of the aircraft parts required more thorough rinsing than those stripped using cyanide.

B. FIELD TESTING OF THE GENERIC NICKEL STRIPPER

This year, field testing was confined to one generic nickel stripping formulation. This stripper was designed to strip electrolytic nickel plates and gave remarkable stripping rates for this plate material. This stripper also worked well on electroless nickel coatings with a moderate to low phosphorus content. This effect on electroless nickel was not known until the field testing was several weeks old. As stated previously in the Results section of this report, the electroless nickel plated coupons purchased this year show a marked resistance to stripping by any means (neither commercial nor generic strippers touch it). As soon as we started reusing old coupons from last year, the electroless nickel stripping was observed and quantified. This generic stripper has stripping rates comparable to Metalx B-9 Nickel Stripper when considering the expected enhancement of stripping rate with temperature (B-9 was tested at 140°F while the generic stripper was tested at 130°F).

Conclusions to be derived from this year's testing include:

1. The generic nickel stripper developed last year and field tested this year should be implemented. It is comprised of the following ingredients: ethylenediamine (20 percent by volume), sodium *m*-nitrobenzenesulfonate (10 percent by weight), concentrated nitric acid (7 percent by volume), and sodium thiocyanate (0.1 percent by weight).
2. This stripper is exceptional for stripping electrolytic nickel and acceptable for stripping electroless nickel plates of moderate to low phosphorous content. It is safe for all basis metals when operated in the suggested pH range. The basis metals tested include: 17-4PH, 316, and 410 stainless steels; C4340 and D6AC low alloy steels; Haynes 188 cobalt alloy; and Inconel 718 nickel alloy.
3. The optimal temperature recommended for stripping electrolytic nickel is 130°F and for stripping electroless nickel as high as permissible. The use of higher temperatures should be tempered with the knowledge that higher temperatures will undoubtedly lead to increased maintenance of the solution and an overall shortened lifetime for the bath.
4. The optimal pH as determined from testing is in the range of 10.0 to 10.5. This is obtained using 7 percent nitric acid in the formulation.
5. The bath is capable of being regenerated by addition of starting materials, particularly sodium *m*-nitrobenzenesulfonate.
6. The loading tests have demonstrated the capability of the bath to function with incredible amounts of nickel in solution; the bath will continue to strip electrolytic nickel at the rate of almost 1 milliinch per hour even with 5 ounces per gallon of nickel in solution.

C. DEVELOPMENT OF GENERIC ELECTROLESS NICKEL STRIPPER

The development of a generic electroless nickel stripper was laden with problems. The electrochemical techniques proved to be of only limited value since oxidizing agents appear to be important to the formulation and presented

interference with the electrochemical analysis. Another difficulty was encountered when attempting to jar test the formulations for electroless nickel stripping since different batches of electroless nickel coupons gave different stripping rates.

The use of electrochemistry works well for analyzing the stripping rates obtained using electrolytic nickel plates; however, the parallel to electroless nickel stripping is not as obvious. Those strippers that strip electrolytic and electroless nickel are the only ones we have been able to identify using these techniques. If further testing by this method were to be contemplated, it is suggested that the proper electrode materials be made. This would mean plating the surface of the electrode with electroless nickel before testing the solutions.

Of the solutions which were identified as potential electroless nickel strippers, one contained glycine as complexation agent while the other contained sodium citrate. The glycine containing stripping bath is similar in composition to the commercial product Metalx B-9 with similar stripping rates and so was not tested further. The solution containing sodium citrate had an electroless nickel stripping rate that was comparable to, although slightly lower than, the glycine formulation. It was also discovered by electrochemical investigation, and later jar tests, that the addition of ethylenediamine to either stripping solution resulted in an increase in stripping rate for both electroless and electrolytic nickel. The greatest increase was observed for the electrolytic plate. The addition of ethylenediamine to enhance the stripping rate also worked with Metalx B-9 Nickel Stripper. This process to enhance the B-9 stripper may be worth further investigation.

When it was discovered that the generic electrolytic nickel stripper also stripped electroless nickel, it was decided to optimize that stripper for electroless nickel stripping. If the same solution could be used to strip both plates, this would allow one tank to be used for two applications. The tests to determine the optimal concentration of ingredients to optimize the electrolytic nickel stripper for electroless nickel stripping were inconclusive. This was because of the problem with the electroless nickel

plates. Therefore, any attempts to look for small changes of stripping rate were worthless, and the attempt to optimize the formulation was impossible.

D. BIOLOGICAL TREATMENT OF NONCYANIDE METAL STRIPPER WASTES

The following conclusions can be drawn from the results of laboratory tests conducted this year:

1. The two primary organic components of noncyanide metal strippers (ethylenediamine and sodium *m*-nitrobenzoate) can be biodegraded in the current IWTP waste stream matrix.
2. The efficiency of removal of ethylenediamine and *m*-nitrobenzoate is very poor at a fluid retention time of 5.3 hours or less. An 8.3 hour fluid retention time provides more efficient removal.
3. Biodegradation of ethylenediamine and *m*-nitrobenzoate occurs within the pH window of 8.5 to 7.0, but is more efficient at pH 7.0.
4. Biodegradation of ethylenediamine and *m*-nitrobenzoate gives rise to elevated effluent ammonia and nitrate concentrations which will very likely cause NPDES violations if full-scale treatment occurs at the Kelly AFB IWTP.
5. Ethylenediamine never appears as a mono-constituent in noncyanide metal stripper formulations, neither do the nitroaromatic compounds. Each of these two components, when mixed together (as in CLEPO 204), can be biodegraded. Combination of these two components also gives rise to an intensely colored component which cannot be removed by the current activated-sludge culture under extended contact times. This yields wastewater that is too intensely colored for discharge.
6. Neither ethylenediamine, nor *m*-nitrobenzoate, had any noticeable malignant effects upon biological activity. The presence and

biodegradation of these two compounds did not have any noticeable malignant effects upon treatment of other waste stream components.

7. The currently used ferrous sulfate/sodium sulfide metals precipitation is inefficient for removing heavy metals from spent CLEPO 204 solutions.

E. COLORED WASTEWATER

The problem encountered in the past by the IWTP at Kelly AFB concerning the discharge of colored wastewater from metal finishing operations has undergone rudimentary investigation - mostly in the library. The literature lists numerous potential sources for the red coloration observed in the plating solutions currently being used and those recommended for use in the plating shop at KAFB. These solutions contain ethylenediamine and sodium *m*-nitrobenzenesulfonate as key ingredients. The literature suggests that the ethylenediamine can form a red compound with sulfur - a component of the electrolytic nickel plates. Another potential source of red coloration is the sodium *m*-nitrobenzenesulfonate which reacts with reducing agents (in this case nickel metal) and may form deep-red colored diazo dyes. The dye chemists use sodium dithionite (hydrosulfite) to reduce the N=N functionality and this may provide a simple chemical means to destroy the red coloration observed in plating wastewater. Yet another colored species is the nickel dissolved in the solution. In the presence of amines, in this case glycine and ethylenediamine, nickel forms dark blue or purple species. These may also contribute to the observed coloration. This coloration would be destroyed in acidic solution and would also be eliminated by the metals treatment process. With this large number of possible sources of coloration, it is recommended that a full investigation take place next year which specifically targets the stripping solutions that are being used and will require waste treatment in the near future.

SECTION VI RECOMMENDATIONS

The following recommendations are based upon observations and test results obtained during the past year's work. They are meant to function as a reiteration of the results and to suggest the next logical step toward achieving self-sufficiency within the Air Force to comprehensively replace cyanide strippers with noncyanide alternatives. The recommendations also serve to help the Air Force realize the full benefit of noncyanide metal stripping technology and achieve the underlying goal of waste minimization.

A. IMPLEMENTATION OF COMMERCIAL STRIPPERS

1. Metalx, Inc. B-9 Nickel Stripper

Based upon favorable implementation test results, Metalx B-9 Nickel Stripper is being recommended for replacement of the cyanide based nickel stripper (C-106) called for in T.O. 42C2-1-7, Table 13-1, Step 3. This is specifically for applications requiring the stripping of electroless nickel from steel parts in the temperature range of $60 \pm 2^\circ\text{C}$ ($140 \pm 5^\circ\text{F}$). An AFTO Form 22 has been prepared and is included in Appendix K for use in changing the required Technical Orders. The benefits that the Air Force can realize with the use of Metalx B-9 Nickel Stripper, in place of the immersion cyanide stripper (C-106), are improved worker safety, less waste generation through extended bath life, and better stripping characteristics.

The testing of this stripper has revealed some weaknesses of which the Air Force needs to be aware. One problem encountered during the implementation testing of this stripper was a recurrent overheating of the bath. This was caused by failure of the air compressor used in the plating shop at Kelly AFB. In addition to overheating, on at least one occasion, the agitation failed after more stripper was added to the bath. The effects of these abuses cannot be adequately determined; however, the results are not entirely indicative of the true potential of this stripper. What is apparent

is that the bath is sensitive to misuse and/or abuse and should be monitored more than just casually. The second batch of stripper was not overheated, gave steady stripping rates, and was free from any adverse corrosion effects.

2. McGean-Rohco, Inc. Rostrip 999-SP Electrolytic Silver Stripper

McGean-Rohco Rostrip 999-SP Electrolytic Silver Stripper is being recommended to replace the Air Force Electrolytic Cyanide stripping process (C-101) for applications requiring silver stripping from steel parts. This is a direct result of excellent behavior observed during implementation testing. Tests using aircraft parts have revealed excellent silver stripping rates (over 8 milliinches per hour) and excellent basis metal protection. Since it contains only inorganic salts (sodium nitrate, sodium nitrite, and sodium hydroxide), it does not require treatment for waste organics. An AFTO Form 22 has been included in Appendix K for changing the required Technical Orders (T.O. 42C2-1-7, Table 16-1, Step 3).

This stripper can be used for stripping silver from low-alloy and stainless steel parts, but is not recommended for use with either Haynes or Inconel basis metals. One adverse property of this stripper is that it is run at an alkaline pH to protect the low alloy steel basis metals, but this condition leads to massive precipitation of silver from the solution as a grey-black sludge. While this keeps the stripped silver out of solution (eliminating loading problems), it makes it harder to inspect the parts, especially when the solution is vigorously agitated. This should not present a problem for the plating shop since this stripper performs equally well without agitation.

With the incorporation of this stripper into the plating shop at Kelly AFB, the last cyanide stripper can be removed. The shop currently maintains an electrolytic cyanide stripper (C-101 process) for stripping of silver from low-alloy steel parts. The presence of this 5700 liters (1500 gallons) of cyanide stripper was due to the fact that there were no acceptable alternatives for silver stripping. With the incorporation of Rostrip 999-SP, the Air Force can meet its goal of total elimination of cyanide stripping solutions from its plating operations.

B. FIELD TESTING OF THE GENERIC NICKEL STRIPPER

We are recommending the following nickel stripper be implemented into the plating shop at Kelly AFB during the next year. The formulation consists of: ethylenediamine (20 percent by volume), sodium *m*-nitrobenzenesulfonate (10 percent by weight), concentrated nitric acid (7 percent by volume), and sodium thiocyanate (0.1 percent by weight). This solution works exceptionally well at removing electrolytic (sulfamate) nickel plates and works relatively well at removing electroless nickel plates as long as the phosphorus content remains relatively low (less than about 8 percent).

We have found, during investigations into the electroless nickel stripping, that the type of electroless nickel plate material can greatly affect the observed stripping rate. Therefore, it is recommended that during next year's testing, the coupons be plated by the Kelly AFB plating shop and these coupons be used to test the implemented stripper. Panels plated at Kelly AFB have been tested and these show stripping rates equivalent to, and sometimes greater than, the coupons labelled as Ni-P* which were used during Phase III testing.

It would also be interesting to determine what concentration of phosphorus in the plate will cause to the stripper to stop working. To determine this, a number of coupons with different electroless nickel coatings would need to be purchased, analyzed for phosphorus content, and then tested. Presently it is known that this stripper will work for removal of electrolytic nickel, the phosphorus nickel plated at Kelly AFB, Nickel-Boron, NiBron, and Niklad 797; however, the phosphorus content limitations will need to be determined if this stripper is going to be fully recommended for use at any other Air Force Bases (other than Kelly), or even commercial plating shops.

C. DEVELOPMENT OF GENERIC ELECTROLESS NICKEL STRIPPER

The testing of electroless nickel strippers was hindered by the inconsistent nature of the electroless nickel coating. The variability of stripping rate has resulted in muddled and confusing data. This has forced us

to recommend that before meaningful results can be obtained for testing of electroless nickel strippers, a consistent set of coupons with exactly the same plate must be prepared. This may be difficult since the plate would need to have significant depth, and electroless nickel baths are known to plate with varying phosphorus content depending on the age of the bath. This implies that there would be a problem with obtaining a consistent plate using the same plating solution since the concentration of electroless nickel bath components will steadily decrease with the amount of nickel plated. This could lead to variable phosphorus content across the depth of the plate as it coats onto the coupon.

D. BIOLOGICAL TREATMENT OF NONCYANIDE METAL STRIPPER WASTES

There are several recommendations to be made concerning waste treatment which have far-ranging implications. These recommendations are based both upon the results obtained from the laboratory experiments and the observations made while conducting operations at the Kelly AFB IWTP during the past two years.

1. The Kelly AFB IWTP

Several recommendations can be made regarding the Kelly AFB IWTP. The first is that Kelly AFB personnel should review their strategy for on-site treatment of wastes. Some of the major waste stream components which existed when the IWTP was built are no longer present. These wastes have been replaced by a number of different organic chemicals which were not considered when the IWTP was designed. Furthermore, none of these chemicals ever received testing (beyond cursory inspection of COD) to determine their effect on current waste treatment processes. The exception is the "red water" problem which received a vigorous investigation by IWTP personnel. As the waste stream grows in volume, and diversifies in content, the methodology used to treat the waste will have to adjust, diversify, and expand as well. The problem lies in the fact that the IWTP design allows for little or no diversification, or expansion.

The second recommendation is that a complete evaluation of the IWTP treatment process should be done from a chemical, biological, and wastewater treatment engineering standpoint. An IWTP system upgrade may be required to provide proper treatment of a growing and diversifying waste stream. More stringent disposal requirements should be put into place which regulates upstream release schedules, quantities, and chemical components. All chemicals currently being disposed into the waste treatment facility should be tested for system compatibility, effects on metals precipitation chemistry, and effects on biological activity. Any chemicals targeted for future release and treatment at the IWTP should undergo testing for treatment system compatibility.

The justification for these recommendations is that it has been observed that the IWTP has been operating at a capacity which exceeds its waste treatment capability. This was not the original intent of the treatment design. The IWTP waste stream has gone from a few organic constituents a year ago (mainly phenol and sodium *m*-nitrobenzenesulfonate) to a variety of different organic constituents which vary in concentration and frequency of occurrence. This is primarily due to contributions from the paint stripping and metals processing waste streams. TOC and COD samples taken from the metals finishing waste equalization basins (P1000 and P1100) indicate that the average TOC and COD of that waste stream is 200 ppm TOC and 400 ppm COD. The effluent from metals treatment and the treated paint stripping wastes are added to the "raw" wastewater that is collected from the entire base. The average daily flow rate of the "raw" waste stream is 1.3 million gallons per day and averages a TOC of 67 ppm and a COD of 57 ppm. There is an inherent problem with diluting the waste from the metals plating shop (low volume, moderate organic concentration) with 1.3 million gallons per day of "raw" wastewater (high volume, low organic concentration). The problem is that the dilution results in the lack of treatment, and the lack of treatment results in the discharge of untreated wastes to the environment.

The fluid retention time has decreased in the main IWTP activated-sludge basins to an average of 4.5 hours. Laboratory experiments conducted this past year indicate that a contact time of 4.5 hours provides poor treatment efficiency at best. This implies that the wastes from the plating

shops, which are added into the "raw" waste stream, are diluted before passing through the activated-sludge basins and inadequately treated. In light of this problem, treatment of noncyanide metal stripping wastes can not be recommended for the central IWTP.

Further evidence comes from wastewater samples collected from the main IWTP activated-sludge influent stream. The data shows that during a 38 day period, the highest influent TOC reading was 103.3 ppm and averaged 66.7 ppm. The influent COD ranged from a high of 204 ppm and averaged 57 ppm. The effluent data shows that the TOC ranged from a high of 85.7 ppm and averaged 54.8 ppm. The effluent COD ranged from a high of 123 ppm and averaged 33 ppm. By calculation, the system was operating at 17.8 percent TOC removal efficiency and 42 percent COD removal efficiency. This implies that not only is the IWTP operating inefficiently, but that wastes are being diluted to insufficient concentrations for stimulating catabolic activity. The central IWTP activated-sludge was not intended to provide treatment for the waste stream which it is now experiencing. However, no effluent NPDES violations can be found because the large volume of water (1.3 million gallons per day) dilutes everything to an average influent TOC of 66.7 ppm and influent COD of 57 ppm. The Kelly AFB IWTP NPDES limit for effluent COD is 100 ppm at a flow rate of 1.3 million gallons per day, and 75 ppm for a flow rate of 1.75 million gallons per day.

The IWTP frequently experiences upsets in both the paint stripping activated-sludge basins and the main IWTP activated-sludge basins. Chemicals, such as surfactants, are discharged to the IWTP which cause foaming problems as well as causing upset conditions in the activated-sludge basins. It is possible that these chemicals are being passed through the system without treatment. There is evidence to support this claim in the experimental data collected during the past year. On several occasions, foaming agents in the waste stream caused disruption of the experiments by decreasing the respiration rate of the biomass, increasing the effluent COD and TOC, and decreasing the biomass concentration in the bioreactors (as well as causing a foamy mess). At the same time, an unknown organic peak appeared on the HPLC chromatograms for the influent and effluent samples. The unknown organic component disappeared first in the influent, then several turnover periods

later it disappeared in the effluent. The problem with excessive foaming occurred only when this organic component was present and was never observed in its absence. The disappearance of the chemical after several turnovers indicates that the component passed through the system without being treated. Treatment efficiency of ethylenediamine and *m*-nitrobenzoate also decreased during these periods. Because test conditions paralleled the IWTP treatment process, although on a smaller scale, it was assumed that the IWTP experienced the same upset and treatment failure. What is the origin of this chemical? What is the chemical? These types of undesirable intrusions have disastrous effects on the biological treatment system. In light of this problem, it cannot be recommended, at this time, that noncyanide metal stripping wastes be treated in the central IWTP.

2. CLEPO 204 Metal Stripping Wastes

The spent noncyanide metal stripping product CLEPO 204 contains ethylenediamine (33 percent volume to volume), sodium *m*-nitrobenzoate (10 percent weight to volume), and a highly colored component. The two major organic components can be biodegraded, but the effluent is still too highly colored to be discharged. It is recommended that the colored components be identified, characterized, and a method for their destruction developed. Otherwise, on-site waste treatment of spent CLEPO 204 solutions will have to pursue a route other than biological treatment. It is not recommended that pilot-scale testing of CLEPO 204 wastes, or the individual organic components (ethylenediamine or *m*-nitrobenzoate), be pursued until the colored component is identified and a method for its treatment is developed. The justification for this is that ethylenediamine will not appear by itself in waste solutions, but as a mixture with nitroaromatic compounds and vice versa. This mixture has been shown to give rise to a colored by-product when used in metal stripping baths. Therefore, the next logical step from bench-scale experimentation of CLEPO 204 would be pilot-scale treatment of the mixture as it will be seen in waste solutions.

Full-scale IWTP treatment of this metal stripping waste is not recommended for the following reasons: a) a minimum fluid retention time of 8 hours is required for wastes containing ethylenediamine and/or *m*-nitro-

benzoate, b) the IWTP cannot achieve an 8 hour retention time in the main activated-sludge basins under normal operations, c) biodegradation of ethylenediamine and *m*-nitrobenzoate results in increased effluent ammonia and nitrate concentrations, d) the IWTP is operating inefficiently and frequently experiences upsets, e) the activated-sludge can be acclimated to ethylenediamine and *m*-nitrobenzoate but frequent upset and unregulated intrusion of incompatible chemicals will cause treatment failure, and f) too much dilution will occur if 6,500 gallons of spent CLEPO 204 waste is added to a 1.3 million gallons per day "raw" wastewater flow.

It is recommended that treatment of CLEPO 204 wastes occur in a small-scale treatment facility similar to the pilot-plant. Parameters such as retention time, dilution rate, and flow rate can be more stringently dictated using a small-scale system. Furthermore, effluent nitrate and ammonia generated by a small-scale system can be utilized as nutrients when fed into the central IWTP activated-sludge.

3. Biodegradability and Compatibility Testing

It is recommended that each chemical (or product) used in upstream processes and disposed to the IWTP be tested for biodegradability and compatibility. Kelly AFB does not currently dedicate enough equipment or facilities to performing these crucial tests. Data obtained from biodegradability and compatibility testing can be used to authorize or forbid disposal of a chemical to the IWTP. This type of testing should decrease the frequency of inefficient and incomplete waste treatment, treatment system upset and failure, and possible NPDES violations. When compared to the liability of discharging untreated wastes, biodegradability and compatibility testing is highly desirable.

A stern warning is to be given here regarding biodegradability, compatibility, and manufacturer product bulletins. Many of the products being used in the metal finishing and paint stripping facilities are categorized as "biodegradable" in the manufacturers' product bulletins. Be warned that although the term "biodegradable" is used, it does not guarantee that the chemical can be successfully treated in the Kelly AFB IWTP. It may be

inherently biodegradable but the conditions under which the chemical is biodegraded may or may not exist at the Kelly AFB IWTP. The manufacturers cannot comment on the effects this product will have upon existing waste treatment methodologies used at the Kelly AFB IWTP. For example, the use of a new chemical may cause interference with metals precipitation. The manufacturers' product bulletin also reveals nothing about the by-products from biodegradation of the chemical. An example of this is ethylenediamine giving rise to excessive effluent ammonia. The manufacturers' product bulletin says nothing about undesirable by-products which are generated from the use of their product. An example of this is CLEPO 204 and the "red water" problem. Some product bulletins claim "biodegradability" and the product contains no organic chemicals, only inorganic acids and salts. The catch here is that some inorganic acids and salts make significant contributions to effluent nitrate, ammonia, and phosphate levels.

These problems can be overcome by testing for compatibility with the waste treatment facility. Compatibility testing provides data to determine the effects a particular chemical will have upon the existing waste stream. From this data, recommendations can be made regarding the best method for treatment and/or disposal. Compatibility testing is just as important as the performance testing of a product for stripping, plating, or other production applications. Without compatibility testing, waste minimization efforts can be defeated, waste treatment system failure can occur, and discharge of an untreated hazardous chemical to the environment will result.

4. Other Metal Stripping Product Testing

It is recommended that laboratory-scale compatibility experiments be conducted on stripping solutions either already implemented, or recommended for implementation into the plating facility.

E. COLORED WASTEWATER

The problem with "red water" is a recurring theme. All of the nickel strippers tested this year turned dark red with use. This type of coloration may also occur in other process solutions that require the use of corrosion inhibitors (e.g., sodium *m*-nitrobenzenesulfonate). Since each solution has different components, and all turn red, there must be a common or at least similar agent responsible for the coloration. The suggested step is to fund research into the possible eradication of this coloration by any known means. The most reliable method would be to isolate and identify the component causing the red coloration. From this information, literature could be used to determine chemical or biological methods for destruction. Other alternatives would include random testing of a wealth of chemical oxidizers and/or reducing agents, biodegradation, or metal precipitation processes for their effect upon the red colored solution.

SECTION VII

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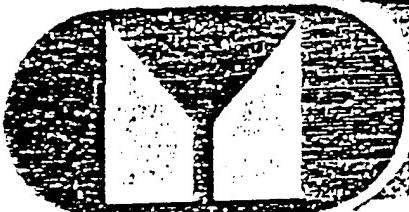
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APPENDIX A

**PRODUCT INFORMATION FOR COMMERCIAL AND GENERIC NONCYANIDE
STRIPPERS TESTED DURING PHASE I (FY-91)**



Data Sheet

McGean-Rohco, Inc.

ROHCO DIVISION

Rosstrip[®] Electrolytic Stripper 999-SP

General Description

A powdered electrolytic stripper to remove copper, nickel, and other metals from steel parts when electrolytic current is used. This product does not contain cyanides or amines which cause problems in disposal.

Advantages

1. Strips chrome and nickel in the same solution.
2. Operates at room temperature.
3. Low carbon steel can be replate without polishing.
4. Easy to operate.
5. No objectionable odors are generated even at high pH.

Operating Conditions

1. 1-2 pounds per gallon of water (120-240 g/l).
2. pH range 12-14.
3. Use stainless steel cathodes.
4. Operate at 80-100°F, (26-38°C) (Higher temperatures will result in pitting. Use steel cooling coils to reduce temperature).
5. Current density should be at least 100 ASF.
(10 amp per sq. dm).
6. A 6-9-volt rectifier is required.

Tank

Steel - Depth should be 1/3 deeper than the longest rack to allow sludge to settle.

Current

Reverse - (Part is anode).

Rack

Mild steel or 300 series stainless steel tips. Do not use copper tips. Be sure rack spline and copper area are completely covered by rack coating. Copper rack hooks should be plastisol covered well above solution level.

McGEAN-ROHCO, INC. - 2910 HARVARD AVE. - P. O. BOX C9087 - CLEVELAND, OHIO 44109 (216) 441-4200, TELEX 24-1124
BEFORE USING ANY OF THESE PRODUCTS, PLEASE OBTAIN A MSDS SHEET FROM THE MANUFACTURER AND REVIEW COMPLETELY
24MIL/1AR WITH THE SAFETY/HAZARD INFORMATION

The information contained herein is presented without guarantee or warranty & 1 The Seller disclaims any liability incurred from the use thereof.
Nothing contained herein is to be construed as a recommendation for its commercial processes and applications by the Seller. Oct/17/80
which is in violation of any existing patent, license or commercial, or other rights of others. THE SELLER MAKES NO WARRANTIES,
EXCEPT AS PROVIDED IN THE CONTRACT OF SALE, OR MERCHANTABILITY AND FITNESS FOR
THESE PURPOSES, EXCLUSIVELY ASSTED IN THE CONTRACT OF SALE. ACKNOWLEDGMENT FORM

Rostrip[®] Electrolytic Stripper 999-SP
Page 2 of 3

Control

1. Pipette 2 ml sample of solution into a 250 ml Erlenmeyer flask, and add 50 mls of distilled water.
2. Pipette 25 mls of 0.1N ceric ammonium sulfate into flask then add 10 mls of 50% hydrochloric acid.
3. Add 1-2 drops ferroin indicator.
4. Back titrate with ferrous ammonium sulfate 0.1 Normal until solution changes from green to rose.

Calculation

25 minus mls of 0.1N ferrous times 2.56 equals oz/gallon Rostrip Electrolytic Stripper 999-SP.

Oz/gallon times 7.5 equals g/l.

Desludging

Allow sludge to settle in a separate tank. Decant off clear liquid and return to stripper tank. Sludge may be concentrated by use of plate and frame filter.

Handling Considerations

Rostrip Electrolytic Stripper 999-SP is a strong oxidizer, which contains nitrates. Store away from cyanide, combustible materials, organics, reducing agents, and acids. Store in cool dry area.

DANGER: This product contains caustic which is corrosive. When handling this product, do not breathe dust which is very irritating to the upper respiratory tract. Avoid contact with skin and eyes. Wear clean clothing, chemical goggles, rubber gloves, apron, boots, gauntlets and full face shield.

While making solutions, add product slowly to surface of solution with agitation to avoid splatter or violent eruptions. Do not add to hot solution. Close container when not in use. Use adequate ventilation. Avoid dust or mist. Do not take internally.

First Aid

If skin and/or eyes are contacted with chemical, immediately flush affected area with clean water for 15 minutes. For skin burn and eye contact, get medical attention.



McGean-Rohco, Inc.

1250 Terminal Tower, Cleveland, Ohio 44113, 216/621-6425

MATERIAL SAFETY DATA SHEET

| | | |
|----------------|---|---------------------------------------|
| Product Name: | Rostrip Electrolytic Stripper 999-SP | Emergency Phone No. (313) 872-1800 |
| Plant Address: | 38521 Schoolcraft Avenue, Livonia, MI 48150 | Chemtrec Phone No. 800/424-9300 |
| Prepared By: | M. Arthur Detrisac | Issue Date: 9-17-88 |
| | | Revised Date: |

INGREDIENTS AND HAZARDOUS COMPONENTS

| Material | % | TLV | C.A.S. # | Suspect Carcinogen |
|--------------|-----|------------------------|---------------|--------------------|
| Caustic Soda | 0.9 | 2mg/ M ³ | 1310- 72-2 | No |
| | | | | |
| | | | | |
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| | | | | |
| | | | | |

PHYSICAL DATA

| | | | | | | | |
|--------------------------------------|-----------------------|--------------------------|----------------------------------|------------------------|----|-------|-------------------|
| Boiling Point: | NA | Freezing Point: | NA | Specific Gravity: | NA | pH: | 10% solution 14.0 |
| Vapor Pressure at 20°C: | NA | Vapor Density (Air = 1): | NA | % Volatiles by Volume: | NA | Odor: | None |
| Evaporation Rate (Butyl Acetate = 1) | NA | | Solubility in Water: Appreciable | | | | |
| Appearance and Form: | Blue Powder Granules. | | | | | | |

FIRE AND EXPLOSION HAZARD DATA

| | | | |
|----------------------|----|--------------------------|------------------|
| Flash Point: | NA | Flammable Limits in Air: | NA |
| Test Method: | NA | % By Volume | Upper: Lower: |
| Extinguishing Media: | NA | | |

Special Fire Fighting Procedures: NA

Unusual Fire and Explosion Hazards: May react with amphoteric metals such as aluminum.
Can generate hydrogen which is flammable or explosive.

DOT Classification: Oxidizer, Corrosive Solid, NOS NA 9194 Note: UK = Unknown NA = Not Applicable

HEALTH HAZARD DATA

Effects of Overexposure and Primary Entries to Body: Corrosive to eyes, skin, and human tissue.

Emergency and First Aid Procedures: Immediately flush with plenty of water for at least 15 minutes. If medical attention has not been obtained, continue flushing.
Ingestion: Give milk and plenty of water. Call physician immediately. Do not induce vomiting.

REACTIVITY DATA

Stable Unstable Conditions to Avoid: Do not contact with acids.

Incompatibility — Materials to Avoid: Exothermic heat of solution.
Reacts with strong acid.

Hazardous Decomposition Products: If acidified will give off nitrous oxide.

Hazardous Polymerization: May Occur Will Not Occur

SPILL OR LEAK PROCEDURES

Spills: Sweep up and dispose as caustic soda in a steel container.

Waste Disposal Methods: Dilute with water. Neutralize with dilute acid.

DISPOSER MUST COMPLY WITH FEDERAL, STATE, AND LOCAL DISPOSAL LAWS.

SPECIAL PROTECTION INFORMATION

Respirator: Use dust mask.

Ventilation: Local Exhaust-Normal Rate.

| | | |
|---------------------|---|-----------------------------------|
| Gloves: Neoprene | Eye and Face: Face Mask or Chemical Goggles | Other: Rubber Apron and Boots. |
|---------------------|---|-----------------------------------|

Handling and Storage: Store in dry area away from amphoteric metals, e.g., Aluminum or zinc. Also, store away from strong acids. Do not add to hot water. The chemical may boil over or spatter while adding to water. Add slowly with constant agitation to prevent spatter, boil over, and ensure complete solubilizing. Contains sodium nitrite which will liberate nitrous oxide fumes when made acid.

THIS PRODUCT SAFETY DATA SHEET IS OFFERED SOLELY FOR YOUR INFORMATION, CONSIDERATION AND INVESTIGATION.

McGEAN-ROHCO, INC. PROVIDES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, AND ASSUMES NO RESPONSIBILITY FOR ACCURACY OR COMPLETENESS OF THE DATA CONTAINED HEREIN.

B-9 NICKEL STRIPPER

For removal of Nickel from Steel

PAGE #1

PERFORMANCE AND BATH LIFE

WHEN MIXED IN ACCORDANCE WITH SIMPLE DIRECTIONS AND OPERATED AT THE RECOMMENDED TEMPERATURE, A NEW SOLUTION OF B-9 NICKEL STRIPPERS SHOULD STRIP ELECTROLYTIC NICKEL AT THE RATE OF ONE TO TWO MILS PER HOUR AND SHOULD DISSOLVE 2½ - 6 OUNCES OF NICKEL PER GALLON OF SOLUTION.

THE STRIPPING RATE OF ELECTROLESS NICKEL DEPENDS ON THE PHOSPHORUS CONTENT OF THE PLATE. A PHOSPHORUS CONTENT NOT EXCEEDING 11% SHOULD DISSOLVE AT THE SAME APPROXIMATE RATE AS ELECTROLYTIC NICKEL PLATE.

INSTRUCTIONS ARE INCLUDED ON PAGE #4 FOR FAST, EFFICIENT REMOVAL OF HIGH PHOSPHORUS ELECTROLESS NICKEL.

FOR SUPERIOR REMOVAL OF NICKEL-IRON COSTINGS, A SPECIAL B-9 NICKEL-IRON STRIPPER IS AVAILABLE AND MIXING INSTRUCTIONS ARE INCLUDED ON PAGE #5.

FOR STRIPPING NICKEL FROM BRASS, COPPER, ZINC DIECAST, SILVER, AND GOLD SUBSTRATES, OUR B-929 IS AVAILABLE WITH A STRIPPING PERFORMANCE AT THE SAME FAST RATE AS OUR REGULAR B-9 NICKEL STRIPPER.

CHEMICAL NICKEL STRIPPERS REMOVE THE MOST NICKEL PER GALLON OF SOLUTION WHEN THEY ARE CORRECTLY MAINTAINED. A STRIPPING BATH THAT IS USED LIGHTLY AND KEPT HOT OVER A PROLONGED TIME PERIOD WILL STRIP LESS NICKEL THAN AN IDENTICAL BATH WHICH IS USED QUICKLY. TO PROLONG BATH LIFE, ALLOW ALL B-9 PRODUCTS TO COOL TO ROOM TEMPERATURE WHEN NOT IN USE.

TANKS AND EQUIPMENT

TANKS: TANKS MAY BE UNLINED STEEL, POLYPROPYLENE, BARRELS, OR ANY LINED TANK THAT WILL SURVIVE OPERATIONAL TEMPERATURE.

AGITATION: AGITATION OR CIRCULATION OF THE B-9 STRIPPER SOLUTION IS REQUIRED TO PREVENT STRATIFICATION OF THE BATH. MILD AIR, PUMPED OR STIRRED SOLUTION, MECHANICAL AGITATION OR TUMBLING ARE ALL ADEQUATE METHODS.

HEAT: SOLUTION HEATING IS REQUIRED TO MAINTAIN A RECOMMENDED TEMPERATURE OF 120°-150°F DURING THE STRIPPING OPERATION. TO PROLONG BATH LIFE, HEATING SHOULD BE DISCONTINUED IMMEDIATELY AFTER USE. NOTE: STEAM HEAT IS NOT RECOMMENDED BUT, IF USED, YOU MUST AGITATE THE BATH THOROUGHLY TO REDUCE BOILING OF THE BATH AT THE INTERFACE OF THE HEATER. IT IS RECOMMENDED THAT AGITATION BE DIRECTED AT, OR PLACED UNDER, THE STEAM COILS TO QUICKLY MOVE THE SOLUTION FROM THE HEATING COILS.

REMOVING ELECTROLYTIC NICKEL FROM STEEL
WITH B-9 NICKEL STRIPPER

THERE ARE TWO METHOD OF USAGE OF ALL B-9 PRODUCTS: THE BATCH METHOD AND THE ADDITION METHOD. THE BATCH METHOD IS OFTEN USED BY THOSE OPERATORS WHO WISH TO MAKE UP SMALLER BATHS AS NEEDED AND USE THEM TO COMPLETION, USUALLY REMOVING $2\frac{1}{2}$ - 4 OUNCES OF NICKEL PER GALLON OF SOLUTION. THOSE OPERATORS USING LARGER TANKS WHO NEED TO ACHIEVE GREATER LIFE AND NICKEL CONCENTRATIONS MAY USE THE ADDITION METHOD.

MIXING INSTRUCTIONS - BATCH METHOD

1. FILL THE STRIPPING TANK HALF FULL OF 120° - 150° F WATER.
2. ADD TWO AND ONE-HALF ($2\frac{1}{2}$) POUNDS OF B-9 NICKEL STRIPPER FOR EACH GALLON OF THE TANK'S WORKING CAPACITY.
3. COMPLETE FILLING THE TANK WITH WARM WATER AND STIR WHILE HEATING TO THE OPERATING TEMPERATURE OF 120° - 150° F.
4. CHECK pH OF THE BATH. IT SHOULD BE 9.2 - 9.8. IF LOWER, RAISE THE pH BY SLOWLY ADDING SODA ASH WHILE STIRRING.
5. WHEN THE PROPER pH HAS BEEN ATTAINED, THE PROPER TEMPERATURE REACHED, AND THE POWDER DISSOLVED, THE STRIPPING BATH IS READY TO USE FOLLOW "BATH OPERATION PROCEDURES" OUTLINED BELOW.

MIXING INSTRUCTIONS- ADDITION METHOD

1. FILL STRIPPING TANK HALF FULL OF 120° - 150° F WATER.
2. ADD ONE AND ONE-HALF ($1\frac{1}{2}$) POUNDS OF B-9 NICKEL STRIPPER FOR EACH GALLON OF THE TANK'S WORKING CAPACITY.
3. COMPLETE FILLING THE TANK WITH WARM WATER AND STIR WHILE HEATING TO THE OPERATING TEMPERATURE OF 120° - 150° F.
4. CHECK THE pH OF THE BATH. IT SHOULD BE 9.2 - 9.8. IF LOWER, RAISE THE pH BY SLOWLY ADDING SODA ASH WHILE STIRRING.
5. WHEN THE PROPER pH HAS BEEN ATTAINED, THE PROPER TEMPERATURE REACHED, AND THE POWDER DISSOLVED, YOUR STRIPPING BATH IS READY TO USE.
6. AFTER COMPLETION OF EACH STRIPPING OPERATION, ANALYZE YOUR BATH FOR NICKEL CONTENT USING THE STANDARD MUREXIDE INDICATOR PROCEDURE. (PROCEDURE LISTED BELOW FOR YOUR CONVENIENCE) AFTER COMPLETING YOUR TITRATION PROCEDURE, YOU MAY BRING YOUR BATH BACK TO THE ORIGINAL OPERATING CONDITION BY ADDING .60 POUNDS OF B-9 PER GALLON OF TANK VOLUME PER OUNCE OF NICKEL IN SOLUTION.
7. AFTER STIRRING IN THE ADDITION, COOL TANK UNTIL NEXT USAGE. DO NOT COVER.

BATH OPERATION PROCEDURES

AFTER REMOVING ALL CHROMIUM, IMMERSE PARTS IN THE B-9 STRIPPER SOLUTION. RACKED PARTS SHOULD BE SUSPENDED IN SOLUTION, NOT TOUCHING THE BOTTOM OR SIDES OF THE TANK OR HEATING COILS. PARTS SHOULD BE SLIGHTLY SPACED TO ALLOW CIRCULATION OF STRIPPER SOLUTION AND AVOID POINT-CONTACT PROBLEMS. FOR THE MOST ECONOMICAL OPERATION, IT IS RECOMMENDED THAT THE OPERATOR STRIP AS MANY PARTS AS CAN POSSIBLY BE PUT IN THE TANK AT ONE TIME, FILLING IT TO ITS PART-HOLDING CAPACITY. PARTS CAN BE VERY SUCCESSFULLY STRIPPED IN A ROTATING BARREL AND, IN MOST CASES, THE SMUT WILL BE REMOVED BY THE TUMBLING ACTION DURING THE STRIPPING CYCLE. GOOD SUCCESS HAS ALSO BEEN ACHIEVED WITH AN ENCLOSED STRIPPING SYSTEM, PUTTING HOT WATER, B-9 STRIPPER (IN THE CORRECT QUANTITY) AND THE PARTS IN AN ENCLOSED BARREL AND SLOWLY TUMBLING.

POST TREATMENT

THE BLACK SMUT REMAINING ON STRIPPED PARTS IS A COMBINATION OF NICKEL OXIDES AND NICKEL SULFIDES AND CAN BE REMOVED BY ANY ONE OF THE FOLLOWING METHODS:

1. IF HEXAVALENT CHROMIUM (APP. 1 LB/GAL) OR CYANIDE (APP. 4 OX/GAL) IS IN HOUSE, A POST DIP IN EITHER WILL REMOVE THE NICKEL SMUT.
2. TO REMOVE SMUT FROM STEEL PARTS, THE USE OF REVERSE CURRENT AT SIX OR MORE VOLTS WHILE THE PART IS IN THE STRIP TANK IS EFFECTIVE BUT MAY SHORTEN THE BATH'S LIFE.
3. A SEPARATE BATH MADE UP OF 50% SPENT STRIP AND 50% NEW STRIP (MADE UP AT 1 LB/GAL) WITH REVERSE CURRENT AT SIX OR MORE VOLTS IS BEING WIDELY USED.
4. FOR REMOVAL OF SMUT FROM STEEL, COPPER, OR ZINC DIECAST, THE FOLLOWING FORMULATION WILL QUICKLY REMOVE ALL SMUT WITH NO ETCHING OF THE ZINC OR COPPER:

(A) N.T.A. TRISODIUM SALT: 1/3 - 1/2 LB/GALLON
(NITRILOTRIACETIC ACID - AVAILABLE FROM W.R.GRAVE OR DUPONT)

(B) 35% HYDROGEN PEROXIDE: 5 - 10% BY VOLUME

BECAUSE OF THE SHORT LIFE OF HYDROGEN PEROXIDE, THIS DIP MUST BE MADE UP ON A DAILY BASIS AND THE SAME DISPOSAL METHODS USED FOR ANY CHELATED MATERIAL SHOULD BE FOLLOWED.

5. IF STRIPPING A THIN ELECTROLYTIC NICKEL (.2 - .4 MILS) THE SMUT WILL ALSO BE THIN AND CAN USUALLY BE REMOVED DURING YOUR NORMAL CLEANING PROCESS PRIOR TO REPLATING: ELECTROCLEAN, RINSE, AND ACID DIP. IF RESIDUAL SMUT IS DETECTED AFTER ACID, REPEAT PROCESS.

REMOVING ELECTROLESS NICKEL FROM STEEL WITH B-9 NICKEL STRIPPER

B-9 NICKEL STRIPPERS GIVE SUPERIOR RESULTS WHEN USED FOR REMOVAL OF ELECTROLESS NICKEL COATINGS. WHEN STRIPPING ELECTROLESS NICKEL CONTAINING NO MORE THAN 11% PHOSPHORUS, FOLLOW THE SAME PROCEDURES LISTED ON PAGES #2 AND 3.

WHEN STRIPPING BRIGHT ELECTROLESS NICKEL IN A NEW BATH UP TO HALF LIFE, THE SMUT WILL BE DISSOLVED IF THE PARTS ARE ALLOWED TO REMAIN IN THE BATH FOR 1-2 HOURS AFTER THE STRIPPING IS COMPLETED. THE STRIPPER SOLUTION SHOULD NOT AFFECT THE BASE METAL. THIS PROCESS, HOWEVER, IS NOT AS EFFECTIVE AFTER THE BATH PASSES HALF-LIFE.

FAST REMOVAL OF HIGH PHOSPHORUS ELECTROLESS NICKEL COATINGS (11 - 15%) CAN BE ACHIEVED BY APPLYING 3 VOLTS OF REVERSE CURRENT TO THE PARTS DURING THE STRIPPING CYCLE. THIS ELECTROCHEMICALLY ENHANCED STRIPPING PROCESS IS AN IMPORTANT NEW DEVELOPMENT IN SOLUBILIZING HIGH PHOSPHORUS ELECTROLESS NICKEL DEPOSITS. (PATENTED) THE ELECTRICAL CURRENT IS UTILIZED ONLY TO DISSOLVE THE PHOSPHORUS IN THE DEPOSIT, ALLOWING THE B-9 TO THEN STRIP THE NICKEL. TO APPLY THE REVERSE CURRENT, WE RECOMMEND AN ELECTRICAL D.C. POWER UNIT OF SIX OR MORE VOLTS WITH THE CAPACITY TO PROVIDE TWENTY AMPS PER SQUARE FOOT OF SURFACE AREA. CAUTION: THIS PROCEDURE MAY ETCH A COPPER-BASED ALLOY AND SHOULD BE EMPLOYED FOR STEEL SUBSTRATES ONLY.

YOUR ELECTROLESS NICKEL BATH CONTAINS STABILIZERS WHICH PREVENT BATH COLLAPSE AND SPONTANEOUS PLATEOUT. AFTER STRIPPING, THESE STABILIZERS ARE CONCENTRATED IN THE SMUT. OCCASIONALLY, A STRIPPED PART THAT LOOKS SMUT-FREE ACTUALLY HAS TRAPPED STABILIZERS WHICH CLING INVISIBLY IN THE CRACKS AND PORES OF THE METAL AND MAY CAUSE PITTING WHEN THE PART IS REPLATED. IF PITTING OCCURS, WE HIGHLY RECOMMEND THE ELECTRICAL SMUT REMOVAL PROCESS DESCRIBED IN THE "Post Treatment" SECTIONS (PAGE #3) BE EMPLOYED AFTER STRIPPING.

REMOVING ELECTROLYTIC NICKEL FROM BRASS, COPPER, ZINC DIECAST, SILVER, AND GOLD WITH B-929 NICKEL STRIPPER

THE B-929 NICKEL STRIPPER FORMULATION CONTAINS SULFUR WHICH INHIBITS COPPER CONTAMINATION AND EXTENDS THE LIFE OF YOUR STRIPPING BATH. THE SULFUR CONTENT OF THE BATH SHOULD BE MAINTAINED BY THE PLATER AT A RATE OF ABOUT A 2 OUNCE ADDITION PER SHIFT OF OPERATION OR AS NEEDED BY FREQUENTLY CHECKING THE BATH. IF SULFUR IS FLOATING ON AND IN THE BATH,

CONT.....

NO ADDITION WILL BE NEEDED. YOU NEED NOT WORRY ABOUT ADDING TOO MUCH SULFUR TO YOUR BATH. IT WILL BE USED AS IT IS NEEDED AND AN OVERADDITION WILL HAVE NO ILL EFFECTS ON THE BATH.

AN ADDITIONAL BENEFIT OF THE B-929 FORMULATION IS THE GREAT REDUCTION, OR POSSIBLY COMPLETE ELIMINATION, OF SMUT BUILD-UP, ESPECIALLY ON THE THINNER NICKEL PLATES. THE HYDROGEN PEROXIDE FORMULATION LISTED IN THE "Post Treatment" SECTION OF PAGE #3 WILL EFFICIENTLY REMOVE ANY REMAINING SMUT WITHOUT ATTACK ON YOUR SUBSTRATES.

THE B-929 IS MADE UP AND OPERATED USING EXACTLY THE SAME PROCEDURES AS THE B-9. PLEASE REFER TO PAGES #2 AND #3 FOR COMPLETE INSTRUCTIONS ON MAKE-UP AND OPERATION.

REMOVING NICKEL-IRON PLATE
WITH B-9 NICKEL-IRON STRIPPER

THE ONLY VARIATION IN USAGE OF THE B-9 NICKEL-IRON STRIPPER IS IN THE MAKE-UP:

1. FILL THE STRIPPING TANK HALF FULL OF 120°-150°F WATER.
2. ADD THREE POUNDS OF THE B-9 NICKEL-IRON STRIPPER FOR EACH GALLON OF THE TANK'S WORKING CAPACITY.
3. COMPLETE FILLING THE TANK WITH WARM WATER AND STIR WHILE HEATING TO THE OPERATING TEMPERATURE OF 120°-150°F.
4. CHECK pH OF THE BATH. IT SHOULD BE 9.2 - 9.8. IF LOWER, RAISE THE pH BY SLOWLY ADDING SODA ASH WHILE STIRRING.
5. WHEN THE PROPER pH HAS BEEN ATTAINED, THE PROPER TEMPERATURE REACHED, AND THE POWDER DISSOLVED, YOUR B-9 NICKEL-IRON STRIPPER BATH IS READY TO USE. FOLLOW "BATH OPERATION PROCEDURE" AND "Post TREATMENT PROCEDURES" OUTLINED ON PAGE #3.

DISPOSAL

THE FOLLOWING DISPOSAL METHODS ARE CURRENTLY BEING EMPLOYED BY SOME B-9, B-929, AND B-9 NICKEL-IRON USERS:

1. IN CONSULTATION WITH LICENSED WASTE DISPOSAL COMPANIES, WE HAVE BEEN ADVISED THAT, BECAUSE OF THE NON-TOXIC FORMULATION OF THE B-9 PRODUCTS, THE SPENT SOLUTION IS CLASSIFIED AS INDUSTRIAL WASTE RATHER THAN HAZARDOUS WASTE. THIS CLASSIFICATION RESULTS IN HAUL-OFF CHARGES AS SMALL AS .50/GALLON OR LESS AND IS, IN MANY CASES, MORE ECONOMICAL THAN TREATING WITHIN YOUR FACILITIES. THE OPERATOR SHOULD TAKE CARE THAT HE DOES NOT INTRODUCE CHROMIUM INTO HIS STRIPPING BATH; THEREBY CAUSING THE SOLUTION TO BE CLASSIFIED

CONT.....

AS HAZARDOUS WASTE.

2. THE ADDITION OF VINMET 1140 (SODIUMDIMETHYLDITHIOCARBAMATE) RESULTS IN AN IMMEDIATE PRECIPITATION OF THE NICKEL IN YOUR SPENT STRIPPING BATH, CREATING A SLUDGE WHICH CAN THEN BE PROCESSED THROUGH YOUR FILTER PRESS. THE RESIDUAL LIQUID MAY BE TREATED BY BEING SLOWLY FED (AFTER REVIEW BY YOUR WASTE DISPOSAL CONSULTANTS) THROUGH YOUR WASTE TREATMENT SYSTEM. THE ABOUT NAMED CHEMICAL CAN BE OBTAINED FROM: VINITINGS CHEMICAL COMPANY, 1650 CANTON ROAD, MARIETTA, GA. OR THROUGH YOUR LOCAL B-9 DISTRIBUTOR.
3. PLATING OUT THE NICKEL FROM THE SPENT STRIPPING BATH IS ALSO BEING SUCCESSFULLY EMPLOYED. AGAIN, THE RESIDUAL LIQUID IS SLOWLY FED THROUGH YOUR WASTE TREATMENT SYSTEM. SOME OPERATORS MAY WANT TO EMPLOY THIS PLATE-OUT TREATMENT ALONG WITH A CHEMICAL TREATMENT.
4. VARIOUS OTHER METHODS OF NICKEL REMOVAL INCLUDE CELLULOSE XANTHATE CHEMICAL PRECIPITATION, ION EXCHANGE, AND SULFIDE PRECIPITATION.

TO ANALYZE YOUR STRIPPING BATH FOR NICKEL CONTENT

REAGENTS NEEDED: CONCENTRATED AMMONIUM HYDROXIDE

MUREXIDE MIX (1 GRAM OF MUREXIDE MIXED WITH 100
GRAMS OF CP SODIUM CHLORIDE)

E.D.T.A. (DISODIUM DIHYDRATE SALT) 0.1M, 37.2350
GRAMS PER LITER

PIPETTE A 10 ML SAMPLE INTO A 250 ML ERLENMEYER FLASK. DILUTE TO 100 ML WITH D.I. WATER. ADD 10 ML AMMONIUM HYDROXIDE. ADD MUREXIDE MIX IN A QUANTITY EQUAL IN SIZE TO THE HEAD OF A LARGE KITCHEN MATCH. TITRATE WITH 0.1M E.D.T.A. TO A VIOLET-PURPLE END POINT.

CALCULATION: NUMBER MLS 0.1M E.D.T.A. TITRATED X .078 FACTOR = OZ/GAL NICKEL METAL. ADD .60 LBS NICKEL STRIPPER PER GALLON OF TANK VOLUME PER OUNCE OF NICKEL TO BRING STRIPPING BATH BACK TO ORIGINAL CONDITION.

EXAMPLE: 100 GALLON TANK

ANALYZATION #1: NICKEL ANALYZED AT .50 OUNCES PER GALLON. MULTIPLY .60 X 100 GALLONS X .50 OUNCES NICKEL = 30 LBS REQUIRED ADDITION.

ANALYZATION #2: NICKEL ANALYZED AT TOTAL OF 1.25 OZ/GAL. SUBTRACT THE PREVIOUS ANALYSIS: 1.25 - .50 = .75 OZ/GAL NICKEL ADDED. MULTIPLY .60 X 100 GALLONS X .75 OUNCES NICKEL = 45 LBS REQUIRED ADDITION.

-END-

B-9 NICKEL STRIPPERS

QUICK IDENTIFIER

Common Name: (Used on label and list)

Material Safety Data Sheet

May be used to comply with OSHA's Hazard Communication Standard.
29CFR 1910, 1200. Standard must be consulted for specific requirements.

SECTION 1 -

Name METALX, INC.
Address ROUTE 10, Box 683
City, State, and Zip LENOIR, N. C. 28645

Emergency Telephone No. 704-758-4997

Other Information Code 704-758-4997

Date Prepared 6/86

Signature of Person Responsible for Preparation (Optional)

SECTION 2 - HAZARDOUS INGREDIENTS/IDENTITY

| Hazardous Component(s) (chemical & common name(s)) | OSHA PEL | ACGIH TLV | Other Exposure Limits | (optional) | CAS NO. |
|--|----------|-----------|-----------------------|------------|---------|
|--|----------|-----------|-----------------------|------------|---------|

B-9, B-929, B-9 NICKEL / IRON STRIPPERS

B-9, B-929, AND B-9 NICKEL/IRON NICKEL STRIPPERS ARE PROPRIETARILY COMPOUNDED MATERIALS AND ARE DEEMED A TRADE SECRET UNDER 29 CFR AND, ACCORDING TO 16 CFR, ARE NON-TOXIC ORALLY. THESE PRODUCTS MAY CONTAIN SODIUM CARBONATE (SODA ASH - AS IN LAUNDRY DETERGENT) AND MAY CAUSE EYE/SKIN IRRITATION.

SECTION 3 - PHYSICAL & CHEMICAL CHARACTERISTICS

| | | | | | |
|---------------|-----|---|-------------|------------------------|-----|
| Boiling Point | N/A | Specific Gravity (H ₂ O = 1) | 8.3 LB/GAL. | Vapor Pressure (mm Hg) | N/A |
|---------------|-----|---|-------------|------------------------|-----|

Vapor Density (Air = 1)

Solubility In Water

COMPLETELY SOLUBLE

Reactivity in Water

Appearance and Odor

OFF-WHITE TO YELLOW GRANULAR POWDER

Melting Point N/A

SECTION 4 - FIRE & EXPLOSION DATA

| | | | | | |
|-------------|---------|-------------|---------------------------------------|-----------|-----------|
| Flash Point | 550° F. | Method Used | Flammability Limit in Air % by Volume | LEL Lower | UEL Upper |
|-------------|---------|-------------|---------------------------------------|-----------|-----------|

Auto-Ignition Temperature

N/A

Extinguisher Media

WATER

Special Fire Fighting Procedures

USE WATER ONLY

Unusual Fire and Explosion Hazards

NONE KNOWN

SECTION 5 - PHYSICAL HAZARDS (REACTIVITY DATA)

Stability Unstable Conditions
Stable To Avoid

Avoid temperatures over 500°F.

Incompatibility
(Materials to Avoid)

Oxidizing agents

Hazardous Decomposition Products

Unknown

Hazardous Polymerization Will Not Occur Conditions
 To Avoid

Avoid temperatures over 500°F and oxidizing agents

SECTION 6 - HEALTH HAZARDS

Acute None known 16 CFR part 1500.3 - considered non-toxic orally

Signs and Symptoms of Exposure This product may contain sodium carbonate (soda ash, as in laundry detergent) and may cause eye-skin irritation

Medical Conditions Generally Aggravated by Exposure Persons with severe allergic reactions should avoid all

chemicals. Avoid inhalation of dust.

Chemical Listed as Carcinogen or Potential Carcinogen None National Toxicology Program Yes IARC Monographs No OSHA Yes No

Emergency and First Aid Procedures For eyes and skin, flush with copious amounts of water. If irritation persists, seek medical attention.

| | | |
|-----------------|---------------|-----------------|
| ROUTES OF ENTRY | 1. Inhalation | Non-toxic |
| | 2. Eyes | Slight Irritant |
| | 3. Skin | Slight Irritant |
| | 4. Ingestion | Non-toxic |

SECTION 7 - SPECIAL PRECAUTIONS AND SPILL/LEAK PROCEDURES

Precautions to be Taken in Handling and Storage Safe and acceptable warehouse practices. Avoid temperatures over 500°F.

Other Precautions Biodegradability Information: C.O.O. mgO₂/kg. 331,000 Product is
B.O.O. mgO₂/kg 231,000 deemed biodegradable

Steps to be Taken in Case Material is Released or Spilled Sweep up solids - wash residue into sewer with water.

Waste Disposal Methods (Consult federal, state, and local regulations) Into sewer in accordance with local regulations governing disposal of solid, soluble non-hazardous wastes.

SECTION 8 - SPECIAL PROTECTION INFORMATION/CONTROL MEASURES

Respiratory Protection (Specify Type) OSHA approved nuisance dust mask recommended

Ventilation suggested Local Exhaust suggested Mechanical General Special Other

Protective Gloves recommended Eye Protection recommended

Other Protective Clothing or Equipment None specific

Work/Hygiene Practices Standard safe handling procedures

IMPORTANT Do not leave any blank spaces. If required information is unavailable, unknown, or does not apply, so indicate.

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OHS09560

MATERIAL SAFETY DATA SHEET

OCCUPATIONAL HEALTH SERVICES, INC.
11 WEST 42ND STREET, 12TH FLOOR
NEW YORK, NEW YORK 10036
1-800-445-MSDS (1-800-445-6737) OR
1-212-789-3535

FOR EMERGENCY SOURCE INFORMATION
CONTACT: 1-615-366-2000

SUBSTANCE IDENTIFICATION

CAS-NUMBER 107-15-3

SUBSTANCE: ETHYLEDIAMIINE

TRADE NAMES/SYNONYMS:

1,2-DIAMINOETHANE; 1,2-ETHYLEDIAMIINE; DIAMINOETHANE; ETHYLEDIAMIINE;
BETA-AMINOETHYLAMINE; DIMETHYLEDIAMIINE; 1,2-ETHANEDIAMIINE; STCC 4935628;
UN 1604; C2H8N2; OHS09560

CHEMICAL FAMILY:
AMINE, ALIPHATIC

MOLECULAR FORMULA: H₂-N-C-H₂-C-H₂-N-H₂

MOLECULAR WEIGHT: 60.10

CERCLA RATINGS (SCALE 0-3): HEALTH=2 FIRE=3 REACTIVITY=0 PERSISTENCE=0
NFPA RATINGS (SCALE 0-4): HEALTH=3 FIRE=2 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: ETHYLEDIAMIINE
CAS# 107-15-3

PERCENT: 100.0

OTHER CONTAMINANTS: NONE.

EXPOSURE LIMITS:

ETHYLEDIAMIINE:

10 PPM (25 MG/M₃) OSHA TWA
10 PPM (25 MG/M₃) ACGIH TWA
10 PPM (25 MG/M₃) NIOSH RECOMMENDED TWA
10 PPM (25 MG/M₃) DFG MAK TWA;
20 PPM (50 MG/M₃) DFG MAK 30 MINUTE PEAK, AVERAGE VALUE, 4 TIMES/SHIFT

MEASUREMENT METHOD: XAD-2(R) TUBE; DIMETHYLFORMAMIDE; HIGH-PRESSURE LIQUID CHROMATOGRAPHY WITH ULTRAVIOLET DETECTION; (NIOSH VOL. III # 2540).

10,000 POUNDS SARA SECTION 302 THRESHOLD PLANNING QUANTITY
5000 POUNDS SARA SECTION 304 REPORTABLE QUANTITY
5000 POUNDS CERCLA SECTION 103 REPORTABLE QUANTITY

PHYSICAL DATA

DESCRIPTION: COLORLESS TO YELLOW, VOLATILE, VISCOS, HYGROSCOPIC LIQUID WITH AN AMMONIA LIKE ODOR. BOILING POINT: 243 F (117 C)
MELTING POINT: 48 F (9 C) SPECIFIC GRAVITY: 0.8995 VOLATILITY: 100%
VAPOR PRESSURE: 10 MM @ 20 C EVAPORATION RATE: (BUTYL ACETATE=1) 0.91
PH: 11.9 @ 25% SOLUTION SOLUBILITY IN WATER: SOLUBLE
ODOR THRESHOLD: 10 PPM VAPOR DENSITY: 2.07
SOLVENT SOLUBILITY: SOLUBLE IN ALCOHOL; SLIGHTLY SOLUBLE IN ETHER.
INSOLUBLE IN BENZENE.

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:

DANGEROUS FIRE HAZARD WHEN EXPOSED TO HEAT OR FLAME.

VAPORS ARE HEAVIER THAN AIR AND MAY TRAVEL A CONSIDERABLE DISTANCE TO A SOURCE OF IGNITION AND FLASH BACK.

VAPOR-AIR MIXTURES ARE EXPLOSIVE ABOVE FLASH POINT.

FLASH POINT: 104 F (40 C) UPPER EXPLOSIVE LIMIT: 12.0% @ 100 C

LOWER EXPLOSIVE LIMIT: 2.5% AUTOIGNITION TEMP.: 725 F (385 C)

FLAMMABILITY CLASS(OSHA): IC

FIREFIGHTING MEDIA:

DRY CHEMICAL, CARBON DIOXIDE, WATER SPRAY OR REGULAR FOAM (1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5).

FOR LARGER FIRES, USE WATER SPRAY, FOG OR REGULAR FOAM (1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5).

ALCOHOL FOAM

(NFPA 325M, FIRE HAZARD PROPERTIES OF FLAMMABLE LIQUIDS, GASES, AND VOLATILE SOLIDS, 1984).

FIREFIGHTING:

MOVE CONTAINER FROM FIRE AREA IF YOU CAN DO IT WITHOUT RISK. DO NOT GET WATER INSIDE CONTAINER. APPLY COOLING WATER TO SIDES OF CONTAINERS THAT ARE EXPOSED TO FLAMES UNTIL WELL AFTER FIRE IS OUT. STAY AWAY FROM ENDS OF TANKS. WITHDRAW IMMEDIATELY IN CASE OF RISING SOUND FROM VENTING SAFETY DEVICE OR ANY DISCOLORATION OF TANK DUE TO FIRE. ISOLATE FOR 1/2 MILE IN ALL DIRECTIONS IF TANK, RAIL CAR OR TANK TRUCK IS INVOLVED IN FIRE (1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5, GUIDE PAGE 29).

EXTINGUISH ONLY IF FLOW CAN BE STOPPED. USE FLOODING QUANTITIES OF WATER AS A

FOG; SOLID STREAMS MAY BE INEFFECTIVE. COOL FIRE-EXPOSED CONTAINERS WITH FLOODING AMOUNTS OF WATER APPLIED FROM AS FAR A DISTANCE AS POSSIBLE. AVOID BREATHING VAPORS; KEEP UPWIND.

TRANSPORTATION DATA

DEPARTMENT OF TRANSPORTATION HAZARD CLASSIFICATION 49 CFR 172.101:
CORROSIVE MATERIAL

DEPARTMENT OF TRANSPORTATION LABELING REQUIREMENTS 49 CFR 172.101 AND
SUBPART E:
CORROSIVE

DEPARTMENT OF TRANSPORTATION PACKAGING REQUIREMENTS: 49 CFR 173.245
EXCEPTIONS: 49 CFR 173.244

TOXICITY

ETHYLEDIAMIINE:

IRRITATION DATA: 450 MG OPEN SKIN-RABBIT MODERATE; 10 MG/24 HOURS
OPEN SKIN-RABBIT SEVERE; 675 UG EYE-RABBIT SEVERE; 750 UG/24 HOURS
EYE-RABBIT SEVERE.

TOXICITY DATA: 200 PPM INHALATION-HUMAN TCLO; 300 MG/M3 INHALATION-MOUSE LC50;
4000 PPM/8 HOURS INHALATION-RAT LC100 (AMIHBC); 4000 PPM/8 HOURS
INHALATION-RAT LCLO; 730 MG/KG SKIN-RABBIT LD50; 500 MG/KG ORAL-RAT LD50;
470 MG/KG ORAL-GUINEA PIG LD50; 500 MG/KG SUBCUTANEOUS-RABBIT LDLO;
300 MG/KG SUBCUTANEOUS-RAT LD50; 100 MG/KG INTRAVENOUS-DOG LDLO; 76 MG/KG
76 MG/KG INTRAPERITONEAL-RAT LD50; 200 MG/KG INTRAPERITONEAL-MOUSE LD50;
MUTAGENIC DATA (RTECS); REPRODUCTIVE EFFECTS DATA (RTECS).

CARCINOGEN STATUS: NONE.

LOCAL EFFECTS: CORROSIVE- INHALATION, SKIN, EYE, INGESTION.

ACUTE TOXICITY LEVEL: HIGHLY TOXIC BY INHALATION; TOXIC BY DERMAL ABSORPTION
AND INGESTION.

TARGET EFFECTS: SENSITIZER- RESPIRATORY, SKIN. POISONING MAY AFFECT THE LUNGS,
LIVER, AND KIDNEYS.

AT INCREASED RISK FROM EXPOSURE: PERSONS WITH PREEXISTING ASTHMA OR ALLERGIES.

ADDITIONAL DATA: CROSS-SENSITIZATION MAY OCCUR WITH OTHER ETHYLENEAMINES,
SOME POLYAMINES, AND WITH HYDRAZINE AND PIPERAZINE ANTIHISTAMINES.

HEALTH EFFECTS AND FIRST AID

INHALATION:

ETHYLEDIAMIINE:

CORROSIVE/SENSITIZER/HIGHLY TOXIC.

2000 PPM IMMEDIATELY DANGEROUS TO LIFE OR HEALTH.

ACUTE EXPOSURE- HUMAN EXPOSURE TO 200 PPM FOR 5-10 SECONDS CAUSED FACIAL
TINGLING AND SLIGHT NASAL IRRITATION; 400 PPM CAUSED INTOLERABLE
NASAL IRRITATION. OTHER SYMPTOMS MAY INCLUDE RESPIRATORY TRACT
IRRITATION, COUGH, DYSPNEA, VOMITING, NAUSEA AND PULMONARY EDEMA.
PULMONARY SENSITIZATION, MANIFESTED BY ASTHMATIC BREATHING, MAY OCCUR IN
PREVIOUSLY EXPOSED PERSONS. RATS EXPOSED TO 4000 PPM FOR 8 HOURS DIED

FROM KIDNEY DAMAGE.

CHRONIC EXPOSURE- PROLONGED OR REPEATED EXPOSURE TO NON-IRRITATING LEVELS MAY RESULT IN PULMONARY SENSITIZATION WITH BRONCHIAL ASTHMA. CHRONIC BRONCHITIS HAS ALSO BEEN REPORTED. SYMPTOMS MAY INCLUDE EOSINOPHILIA, WHEEZING, CHEST TIGHTNESS, COUGHING DYSPNEA, SNEEZING, NASAL DISCHARGE, SWEATING, HEADACHES, MALAISE, AND TACHYCARDIA. EXPOSURE TO 484 PPM FOR 20 DAYS CAUSED DEPILATION AND LUNG, KIDNEY AND LIVER DAMAGE, AND DEATH IN RATS.

FIRST AID- REMOVE FROM EXPOSURE AREA TO FRESH AIR IMMEDIATELY. IF BREATHING HAS STOPPED, GIVE ARTIFICIAL RESPIRATION. MAINTAIN AIRWAY AND BLOOD PRESSURE AND ADMINISTER OXYGEN IF AVAILABLE. KEEP AFFECTION PERSON WARM AND AT REST. TREAT SYMPTOMATICALLY AND SUPPORTIVELY. ADMINISTRATION OF OXYGEN SHOULD BE PERFORMED BY QUALIFIED PERSONNEL. GET MEDICAL ATTENTION IMMEDIATELY.

SKIN CONTACT:

ETHYLENEDIAMINE:

CORROSIVE/SENSITIZER/TOXIC.

ACUTE EXPOSURE- DIRECT CONTACT WITH AQUEOUS SOLUTIONS MAY CAUSE SEVERE IRRITATION; UNDILUTED LIQUID MAY CAUSE BURNS. BLISTERING MAY OCCUR AND BE PARTLY DUE TO SENSITIZATION IN PREVIOUSLY EXPOSED PERSONS. ANIMAL STUDIES INDICATE FATAL AMOUNTS MAY BE ABSORBED THROUGH INTACT SKIN. SKIN ABSORPTION IS ENHANCED BY TISSUE DAMAGE.

CHRONIC EXPOSURE- REPEATED OR PROLONGED EXPOSURE MAY CAUSE DERMATITIS DUE EITHER TO IRRITATION OR SENSITIZATION. SENSITIZATION IS MORE LIKELY TO OCCUR WHEN THE SKIN IS DAMAGED.

FIRST AID- REMOVE CONTAMINATED CLOTHING AND SHOES IMMEDIATELY. WASH AFFECTED AREA WITH SOAP OR MILD DETERGENT AND LARGE AMOUNTS OF WATER UNTIL NO EVIDENCE OF CHEMICAL REMAINS (AT LEAST 15-20 MINUTES). IN CASE OF CHEMICAL BURNS, COVER AREA WITH STERILE, DRY DRESSING. BANDAGE SECURELY, BUT NOT TOO TIGHTLY. GET MEDICAL ATTENTION IMMEDIATELY.

EYE CONTACT:

ETHYLENEDIAMINE:

CORROSIVE.

ACUTE EXPOSURE- LOW VAPOR CONCENTRATIONS MAY CAUSE SOME BLURRING OF VISION AND HALOES AROUND OBJECTS. HIGH CONCENTRATIONS MAY CAUSE ACUTE PAIN AND SEVERE IRRITATION. BURNS, CORNEAL DESTRUCTION, AND BLINDNESS MAY RESULTED FROM THE LIQUID. AN AQUEOUS 15% SOLUTION CAUSED SERIOUS CORNEAL DAMAGE TO RABBIT EYES; A 5% SOLUTION CAUSED PARTIAL CORNEAL OPACITY.

CHRONIC EXPOSURE- EFFECTS DEPEND ON CONCENTRATION AND DURATION OF EXPOSURE. REPEATED OR PROLONGED CONTACT WITH CORROSIVE SUBSTANCES MAY RESULT IN CONJUNCTIVITIS OR EFFECTS AS IN ACUTE EXPOSURE.

FIRST AID- WASH EYES IMMEDIATELY WITH LARGE AMOUNTS OF WATER, OCCASIONALLY LIFTING UPPER AND LOWER LIDS, UNTIL NO EVIDENCE OF CHEMICAL REMAINS (AT LEAST 15-20 MINUTES). CONTINUE IRRIGATING WITH NORMAL SALINE UNTIL THE PH HAS RETURNED TO NORMAL (30-60 MINUTES). COVER WITH STERILE BANDAGES. GET MEDICAL ATTENTION IMMEDIATELY.

INGESTION:

ETHYLENEDIAMINE:

CORROSIVE/TOXIC.

ACUTE EXPOSURE- INGESTION MAY CAUSE BURNS OF THE MOUTH AND THROAT, ABDOMINAL PAIN, NAUSEA, AND VOMITING. THE REPORTED LETHAL DOSE IN RATS WAS 500 MG/KG; THE SYMPTOMS WERE NOT REPORTED.

CHRONIC EXPOSURE- THERAPEUTIC USE HAS RESULTED IN SEVERE EXFOLIATIVE DERMATITIS. REPRODUCTIVE EFFECTS HAVE BEEN REPORTED IN ANIMALS. DEPENDING ON THE CONCENTRATIONS, REPEATED INGESTION OF CORROSIVE SUBSTANCES MAY RESULT IN EFFECTS AS WITH ACUTE INGESTION.

FIRST AID: TREAT SYMPTOMATICALLY AND SUPPORTIVELY. IF PERSON IS CONSCIOUS AND ABLE TO SWALLOW, GIVE LARGE AMOUNTS OF WATER OR MILK TO DILUTE SUBSTANCE. GET MEDICAL ATTENTION IMMEDIATELY. GASTRIC LAVAGE PERFORMED BY QUALIFIED MEDICAL PERSONNEL MIGHT BE ADVISABLE IF THERE ARE NO SIGNS OF PERFORATION FROM THE INGESTION OF A CORROSIVE SUBSTANCE. IF VOMITING OCCURS, KEEP HEAD BELOW HIPS TO HELP PREVENT ASPIRATION.

ANTIDOTE:

NO SPECIFIC ANTIDOTE. TREAT SYMPTOMATICALLY AND SUPPORTIVELY.

REACTIVITY

REACTIVITY:

STABLE UNDER NORMAL TEMPERATURES AND PRESSURES.

INCOMPATIBILITIES:

ETHYLENEDIAMINE:

ACETIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ACETIC ANHYDRIDE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ACIDS (STRONG): FIRE AND EXPLOSION HAZARD.

ACROLEIN: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ACRYLIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ACRYLONITRILE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ALLYL CHLORIDE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ALUMINUM: MAY BE CORROSIVE.

CARBON DISULFIDE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

CELLULOSE NITRATE: IGNITES SPONTANEOUSLY.

CHLORINATED HYDROCARBONS: VIOLENT REACTION.

CHLORSULFONIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

DIISOPROPYLPEROXYDICARBONATE: SPONTANEOUS DECOMPOSITION.

EPICHLOROHYDRIN: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ETHYLENE CHLOROHYDRIN: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

HYDROCHLORIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

MESITYL OXIDE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

NITRIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

NITROMETHANE: INCREASED SENSITIVITY TOWARD DETONATION.

OLEUM: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

OXIDIZERS (STRONG): FIRE AND EXPLOSION HAZARD.

BETA-PROPIOLACTONE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

SILVER PERCHLORATE: EXPLOSIVE REACTION.

SULFURIC ACID: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

VINYL ACETATE: TEMPERATURE AND PRESSURE INCREASE IN A CLOSED CONTAINER.

ZINC: MAY BE CORROSIVE.

DECOMPOSITION:

THERMAL DECOMPOSITION PRODUCTS MAY INCLUDE CORROSIVE FUMES OF AMMONIA, AND TOXIC OXIDES OF NITROGEN AND CARBON.

POLYMERIZATION:

HAZARDOUS POLYMERIZATION HAS NOT BEEN REPORTED TO OCCUR UNDER NORMAL TEMPERATURES AND PRESSURES.

STORAGE AND DISPOSAL

OBSERVE ALL FEDERAL, STATE AND LOCAL REGULATIONS WHEN STORING OR DISPOSING OF THIS SUBSTANCE. FOR ASSISTANCE, CONTACT THE DISTRICT DIRECTOR OF THE ENVIRONMENTAL PROTECTION AGENCY.

STORAGE

STORE IN ACCORDANCE WITH 29 CFR 1910.106.

BONDING AND GROUNDING: SUBSTANCES WITH LOW ELECTROCONDUCTIVITY, WHICH MAY BE IGNITED BY ELECTROSTATIC SPARKS, SHOULD BE STORED IN CONTAINERS WHICH MEET THE BONDING AND GROUNDING GUIDELINES SPECIFIED IN NFPA 77-1983, RECOMMENDED PRACTICE ON STATIC ELECTRICITY.

STORE AWAY FROM INCOMPATIBLE SUBSTANCES.

THRESHOLD PLANNING QUANTITY (TPQ):

THE SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT (SARA) SECTION 302 REQUIRES THAT EACH FACILITY WHERE ANY EXTREMELY HAZARDOUS SUBSTANCE IS PRESENT IN A QUANTITY EQUAL TO OR GREATER THAN THE TPQ ESTABLISHED FOR THAT SUBSTANCE NOTIFY THE STATE EMERGENCY RESPONSE COMMISSION FOR THE STATE IN WHICH IT IS LOCATED. SECTION 303 OF SARA REQUIRES THESE FACILITIES TO PARTICIPATE IN LOCAL EMERGENCY RESPONSE PLANNING (40 CFR 355.30).

KEEP IN A TIGHTLY CLOSED CONTAINER. STORE IN A COOL, DRY, VENTILATED AREA.

PROTECT FROM PHYSICAL DAMAGE. STORE IN A COOL, DRY, WELL VENTILATED AREA AWAY FROM ANY AREA WHERE FIRE HAZARD MAY BE ACUTE. OUTSIDE OR DETACHED STORAGE IS PREFERRED. INSIDE STORAGE SHOULD BE IN A STANDARD FLAMMABLE LIQUIDS STORAGE ROOM. SEPARATE FROM OXIDIZING MATERIALS. COPPER OR COPPER-BEARING ALLOYS SHOULD NOT BE USED FOR STORAGE OR HANDLING (NFPA 49, HAZARDOUS CHEMICALS DATA, 1975).

DISPOSAL

DISPOSAL MUST BE IN ACCORDANCE WITH STANDARDS APPLICABLE TO GENERATORS OF HAZARDOUS WASTE, 40 CFR 262. EPA HAZARDOUS WASTE NUMBER D001.

100 POUND CERCLA SECTION 103 REPORTABLE QUANTITY.

CONDITIONS TO AVOID

AVOID CONTACT WITH HEAT, SPARKS, FLAMES OR OTHER IGNITION SOURCES. VAPORS MAY BE EXPLOSIVE. MATERIAL IS CORROSIVE; AVOID CONTACT WITH SKIN OR EYES. DO NOT ALLOW CONTAMINATION OF WATER SOURCES.

SPILL AND LEAK PROCEDURES

SOIL SPILL:

DIG A HOLDING AREA SUCH AS A PIT, POND OR LAGOON TO CONTAIN SPILL AND DIKE SURFACE FLOW USING BARRIER OF SOIL, SANDBAGS, FOAMED POLYURETHANE OR FOAMED CONCRETE. ABSORB LIQUID MASS WITH FLY ASH OR CEMENT POWDER.

USE SODIUM BISULFATE (NA-H-SO₄) TO NEUTRALIZE SPILL.

AIR SPILL:

APPLY WATER SPRAY TO KNOCK DOWN AND REDUCE VAPORS. KNOCK-DOWN WATER IS CORROSIVE AND TOXIC AND SHOULD BE DIKED FOR CONTAINMENT.

WATER SPILL:

LIMIT SPILL MOTION AND DISPERSION WITH NATURAL BARRIERS OR OIL SPILL CONTROL BOOMS.

APPLY DETERGENTS, SOAPS, ALCOHOLS OR ANOTHER SURFACE ACTIVE AGENT.

APPLY UNIVERSAL GELLING AGENT TO IMMOBILIZE TRAPPED SPILL AND INCREASE EFFICIENCY OF REMOVAL.

ADD SODIUM BISULFITE.

IF DISSOLVED, AT A CONCENTRATION OF 10 PPM OR GREATER, APPLY ACTIVATED CARBON AT TEN TIMES THE AMOUNT THAT HAS BEEN SPILLED.

USE MECHANICAL DREDGES OR LIFTS TO EXTRACT IMMOBILIZED MASSES OF POLLUTION AND PRECIPITATES.

OCCUPATIONAL SPILL:

SHUT OFF IGNITION SOURCES. DO NOT TOUCH SPILLED MATERIAL. STOP LEAK IF YOU CAN DO IT WITHOUT RISK. USE WATER SPRAY TO REDUCE VAPORS. DO NOT GET WATER INSIDE CONTAINER. FOR SMALL SPILLS, TAKE UP WITH SAND OR OTHER ABSORBENT MATERIAL AND PLACE INTO CONTAINERS FOR LATER DISPOSAL. FOR LARGER SPILLS, DIKE FAR AHEAD OF SPILL FOR LATER DISPOSAL. NO SMOKING, FLAMES OR FLARES IN HAZARD AREA. KEEP UNNECESSARY PEOPLE AWAY; ISOLATE HAZARD AREA AND DENY ENTRY.

REPORTABLE QUANTITY (RQ): 5000 POUNDS

THE SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT (SARA) SECTION 304 REQUIRES THAT A RELEASE EQUAL TO OR GREATER THAN THE REPORTABLE QUANTITY FOR THIS SUBSTANCE BE IMMEDIATELY REPORTED TO THE LOCAL EMERGENCY PLANNING COMMITTEE AND THE STATE EMERGENCY RESPONSE COMMISSION (40 CFR 355.40). IF THE RELEASE OF THIS SUBSTANCE IS REPORTABLE UNDER CERCLA SECTION 103, THE NATIONAL RESPONSE

CENTER MUST BE NOTIFIED IMMEDIATELY AT (800) 424-8802 OR (202) 426-2675 IN THE METROPOLITAN WASHINGTON, D.C. AREA (40 CFR 302.6).

PROTECTIVE EQUIPMENT

VENTILATION:

PROCESS ENCLOSURE VENTILATION RECOMMENDED TO MEET PUBLISHED EXPOSURE LIMITS. VENTILATION EQUIPMENT MUST BE EXPLOSION-PROOF.

RESPIRATOR:

THE FOLLOWING RESPIRATORS AND MAXIMUM USE CONCENTRATIONS ARE RECOMMENDATIONS BY THE U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, NIOSH POCKET GUIDE TO CHEMICAL HAZARDS; NIOSH CRITERIA DOCUMENTS OR BY THE U.S. DEPARTMENT OF LABOR, 29 CFR 1910 SUBPART Z.

THE SPECIFIC RESPIRATOR SELECTED MUST BE BASED ON CONTAMINATION LEVELS FOUND IN THE WORK PLACE, MUST NOT EXCEED THE WORKING LIMITS OF THE RESPIRATOR AND BE JOINTLY APPROVED BY THE NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH AND THE MINE SAFETY AND HEALTH ADMINISTRATION (NIOSH-MSHA).

ETHYLENEDIAMINE:

250 PPM- ANY SUPPLIED-AIR RESPIRATOR OPERATED IN A CONTINUOUS-FLOW MODE.
ANY POWERED, AIR-PURIFYING RESPIRATOR WITH CARTRIDGE(S) PROVIDING PROTECTION AGAINST ETHYLENEDIAMINE.

500 PPM- ANY CHEMICAL CARTRIDGE RESPIRATOR WITH A FULL FACEPIECE AND CARTRIDGE(S) PROVIDING PROTECTION AGAINST ETHYLENEDIAMINE..
ANY AIR-PURIFYING, FULL-FACEPIECE RESPIRATOR (GAS MASK) WITH A CHIN-STYLE, FRONT- OR BACK- MOUNTED CANISTER PROVIDING PROTECTION AGAINST ETHYLENEDIAMINE.
ANY SELF-CONTAINED BREATHING APPARATUS WITH A FULL FACEPIECE.
ANY SUPPLIED-AIR RESPIRATOR WITH A FULL FACEPIECE.

2000 PPM- ANY SUPPLIED-AIR RESPIRATOR THAT HAS A FULL FACEPIECE AND IS OPERATED IN A PRESSURE-DEMAND OR OTHER POSITIVE- PRESSURE MODE.
ESCAPE- ANY AIR-PURIFYING, FULL FACEPIECE RESPIRATOR (GAS MASK) WITH A CHIN-SYYLE, FRONT- OR BACK-MOUNTED CANISTER PROVIDING PROTECTION AGAINST ETHYLENEDIAMINE.
ANY APPROPRIATE ESCAPE-TYPE, SELF-CONTAINED BREATHING APPARATUS.

FOR FIREFIGHTING AND OTHER IMMEDIATELY DANGEROUS TO LIFE OR HEALTH CONDITIONS:

ANY SELF-CONTAINED BREATHING APPARATUS THAT HAS A FULL FACEPIECE AND IS OPERATED IN A PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE.

ANY SUPPLIED-AIR RESPIRATOR THAT HAS A FULL FACEPIECE AND IS OPERATED IN A PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE IN COMBINATION WITH AN AUXILIARY SELF-CONTAINED BREATHING APPARATUS OPERATED IN PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE.

CLOTHING:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE (IMPERVIOUS) CLOTHING AND EQUIPMENT TO PREVENT ANY POSSIBILITY OF SKIN CONTACT WITH THIS SUBSTANCE.

GLOVES:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE GLOVES TO PREVENT CONTACT WITH THIS SUBSTANCE.

EYE PROTECTION:

EMPLOYEE MUST WEAR SPLASH-PROOF OR DUST-RESISTANT SAFETY GOGGLES AND A FACESHIELD TO PREVENT CONTACT WITH THIS SUBSTANCE.

EMERGENCY WASH FACILITIES:

WHERE THERE IS ANY POSSIBILITY THAT AN EMPLOYEE'S EYES AND/OR SKIN MAY BE EXPOSED TO THIS SUBSTANCE, THE EMPLOYER SHOULD PROVIDE AN EYE WASH FOUNTAIN AND QUICK DRENCH SHOWER WITHIN THE IMMEDIATE WORK AREA FOR EMERGENCY USE.

AUTHORIZED BY- OCCUPATIONAL HEALTH SERVICES, INC.

CREATION DATE: 12/10/84

REVISION DATE: 05/27/91

OHS09560

107-15-3

ETHYLENEDIAMINE

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OHS21700

MATERIAL SAFETY DATA SHEET

OCCUPATIONAL HEALTH SERVICES, INC.
11 WEST 42ND STREET, 12TH FLOOR
NEW YORK, NEW YORK 10036
1-800-445-MSDS (1-800-445-6737) OR
1-212-789-3535

FOR EMERGENCY SOURCE INFORMATION
CONTACT: 1-615-366-2000

SUBSTANCE IDENTIFICATION

CAS-NUMBER 540-72-7

SUBSTANCE: SODIUM THIOCYANATE

TRADE NAMES/SYNONYMS:

SODIUM SULFOCYANATE; SODIUM RHODANIDE; RHODANATE; SODIUM SULFOCYANIDE;
SODIUM RHODANATE; SODIUM THIOCYANIDE; THIOCYANIC ACID, SODIUM SALT;
HAIMASED; SCYAN; SODIUM ISOTHIOCYANATE; S-441; OHS21700

CHEMICAL FAMILY:

INORGANIC SALT

MOLECULAR FORMULA: NA-C-N-S MOL WT: 81.07

CERCLA RATINGS (SCALE 0-3): HEALTH=2 FIRE=0 REACTIVITY=0 PERSISTENCE=0
NFPA RATINGS (SCALE 0-4): HEALTH=2 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: SODIUM THIOCYANATE PERCENT: >98
CAS# 540-72-7

OTHER CONTAMINANTS: SODIUM CARBONATE, AND INSOLUBLE MATTER

EXPOSURE LIMITS:

NO OCCUPATIONAL EXPOSURE LIMITS ESTABLISHED BY OSHA, ACGIH, OR NIOSH.

PHYSICAL DATA

DESCRIPTION: ODORLESS, DELIQUESCENT, CRYSTALS OR WHITE POWDER.

BOILING POINT: DECOMPOSES MELTING POINT: 549 F (287 C)

SPECIFIC GRAVITY: >1.0 PH: AQUEOUS SOLN NEUTRAL

SOLUBILITY IN WATER: SOLUBLE

SOLVENT SOLUBILITY: SOLUBLE IN ALCOHOL, AND ACETONE.

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
NEGIGIBLE FIRE HAZARD WHEN EXPOSED TO HEAT OR FLAME.

FLASH POINT: NONFLAMMABLE

FIREFIGHTING MEDIA:
EXTINGUISH USING AGENT SUITABLE FOR TYPE OF SURROUNDING FIRE.

FIREFIGHTING:
NO ACUTE HAZARD. MOVE CONTAINER FROM FIRE AREA IF POSSIBLE. AVOID BREATHING VAPORS OR DUSTS; KEEP UPWIND.

TOXICITY

SODIUM THIOCYANATE:
764 MG/KG ORAL-RAT LD50; 362 MG/KG ORAL-MOUSE LD50; 750 MG/KG ORAL-RABBIT LDLO; 540 MG/KG INTRAPERITONEAL-RAT LD50; 600 MG/KG ORAL-GUINEA PIG LDLO;
CARCINOGEN STATUS: NONE.

SODIUM THIOCYANATE IS AN EYE, SKIN, AND MUCOUS MEMBRANE IRRITANT. IT AFFECTS THE CENTRAL NERVOUS SYSTEM AND BLOOD PRESSURE. LARGE DOSES MAY CAUSE SKIN ERUPTIONS, PSYCHOSIS, AND COLLAPSE.

HEALTH EFFECTS AND FIRST AID

INHALATION:

SODIUM THIOCYANATE:

NARCOTIC.

ACUTE EXPOSURE- LOW DOSES MAY CAUSE HEADACHE, DROWSINESS, DIZZINESS, NARCOSIS, HYPOTENSION, VISUAL HALLUCINATIONS, CONFUSION AND CYANOSIS.

LARGE DOSES MAY CAUSE PSYCHOSES AND COLLAPSE.

CHRONIC EXPOSURE- NONE REPORTED IN HUMANS.

FIRST AID- REMOVE FROM EXPOSURE AREA TO FRESH AIR IMMEDIATELY. IF BREATHING HAS STOPPED, PERFORM ARTIFICIAL RESPIRATION. KEEP PERSON WARM AND AT REST. TREAT SYMPTOMATICALLY AND SUPPORTIVELY. GET MEDICAL ATTENTION IMMEDIATELY.

SKIN CONTACT:

SODIUM THIOCYANATE:

IRRITANT.

ACUTE EXPOSURE- MAY CAUSE IRRITATION AND PAIN.

CHRONIC EXPOSURE- REPEATED OR PROLONGED CONTACT MAY CAUSE DERMATITIS.

FIRST AID- REMOVE CONTAMINATED CLOTHING AND SHOES IMMEDIATELY. WASH AFFECTED AREA WITH SOAP OR MILD DETERGENT AND LARGE AMOUNTS OF WATER UNTIL NO EVIDENCE OF CHEMICAL REMAINS (APPROXIMATELY 15-20 MINUTES). GET MEDICAL ATTENTION IMMEDIATELY.

EYE CONTACT:

SODIUM THIOCYANATE:

IRRITANT.

ACUTE EXPOSURE- CONTACT MAY CAUSE REDNESS, PAIN, AND IRRITATION.

CHRONIC EXPOSURE- REPEATED OR PROLONGED CONTACT MAY CAUSE CONJUNCTIVITIS.

FIRST AID- WASH EYES IMMEDIATELY WITH LARGE AMOUNTS OF WATER OR NORMAL SALINE, OCCASIONALLY LIFTING UPPER AND LOWER LIDS, UNTIL NO EVIDENCE OF CHEMICAL REMAINS (APPROXIMATELY 15-20 MINUTES). GET MEDICAL ATTENTION IMMEDIATELY.

INGESTION:

ACUTE EXPOSURE- INGESTION MAY CAUSE HEADACHE, NAUSEA, VOMITING, DIZZINESS, FATIGUE, DISORIENTATON, HYPOTENSION, CONFUSION, PSYCHOTIC BEHAVIOR, MUSCULAR SPASMS, CONVULSIONS, CYANOSIS AND DEATH.

CHRONIC EXPOSURE- DERMATITIS, HIVES AND ABNORMAL BLEEDING MAY OCCUR. THE THYROID GLAND MAY ALSO BE ENLARGED.

FIRST AID- REMOVE BY GASTRIC LAVAGE OR EMESIS. MAINTAIN BLOOD PRESSURE AND AIRWAY. GIVE OXYGEN IF RESPIRATION IS DEPRESSED. DO NOT PERFORM GASTRIC LAVAGE OR EMESIS IF VICTIM IS UNCONSCIOUS. GET MEDICAL ATTENTION IMMEDIATELY (DREISBACH, HANDBOOK OF POISONING, 11TH ED.). ADMINISTRATION OF GASTRIC LAVAGE OR OXYGEN SHOULD BE PERFORMED BY QUALIFIED MEDICAL PERSONNEL.

ANTIDOTE:

NO SPECIFIC ANTIDOTE. TREAT SYMPTOMATICALLY AND SUPPORTIVELY.

REACTIVITY

REACTIVITY:

STABLE UNDER NORMAL TEMPERATURES AND PRESSURES.

INCOMPATIBILITIES:

MAY REACT EXPLOSIVELY WITH SODIUM NITRITE UPON HEATING.

DECOMPOSITION:

THERMAL DECOMPOSITION PRODUCTS MAY INCLUDE TOXIC AND HAZARDOUS FUMES OF CYANIDES, AND OXIDES OF NITROGEN, SULFUR AND SODIUM.

POLYMERIZATION:

HAZARDOUS POLYMERIZATION HAS NOT BEEN REPORTED TO OCCUR UNDER NORMAL TEMPERATURES AND PRESSURES.

CONDITIONS TO AVOID

MAY BURN BUT DOES NOT IGNITE READILY. AVOID CONTACT WITH STRONG OXIDIZERS, EXCESSIVE HEAT, SPARKS, OR OPEN FLAME.

SPILL AND LEAK PROCEDURES

OCCUPATIONAL SPILL:

SWEET UP AND PLACE IN SUITABLE CLEAN, DRY CONTAINERS FOR RECLAMATION OR LATER DISPOSAL. DO NOT FLUSH SPILLED MATERIAL INTO SEWER. KEEP UNNECESSARY PEOPLE AWAY.

PROTECTIVE EQUIPMENT

VENTILATION:

PROVIDE LOCAL EXHAUST OR GENERAL DILUTION VENTILATION SYSTEM.

RESPIRATOR:

HIGH LEVELS- DUST, MIST, AND FUME RESPIRATOR.

FIREFIGHTING- SELF-CONTAINED BREATHING APPARATUS WITH A FULL FACEPIECE OPERATED IN PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE.

CLOTHING:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE (IMPERVIOUS) CLOTHING AND EQUIPMENT TO PREVENT REPEATED OR PROLONGED SKIN CONTACT WITH THIS SUBSTANCE.

GLOVES:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE GLOVES TO PREVENT CONTACT WITH THIS SUBSTANCE.

EYE PROTECTION:

EMPLOYEE MUST WEAR SPLASH-PROOF OR DUST-RESISTANT SAFETY GOGGLES AND A FACESHIELD TO PREVENT CONTACT WITH THIS SUBSTANCE.

EMERGENCY WASH FACILITIES:

WHERE THERE IS ANY POSSIBILITY THAT AN EMPLOYEE'S EYES AND/OR SKIN MAY BE EXPOSED TO THIS SUBSTANCE, THE EMPLOYER SHOULD PROVIDE AN EYE WASH FOUNTAIN AND QUICK DRENCH SHOWER WITHIN THE IMMEDIATE WORK AREA FOR EMERGENCY USE.

AUTHORIZED BY- OCCUPATIONAL HEALTH SERVICES, INC.
CREATION DATE: 12/19/84 REVISION DATE: 02/19/91

OHS21700

540-72-7

SODIUM THIOCYANATE

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OHS16540

MATERIAL SAFETY DATA SHEET

OCCUPATIONAL HEALTH SERVICES, INC.
 11 WEST 42ND STREET, 12TH FLOOR
 NEW YORK, NEW YORK 10036
 1-800-445-MSDS (1-800-445-6737) OR
 1-212-789-3535

FOR EMERGENCY SOURCE INFORMATION
 CONTACT: 1-615-366-2000

SUBSTANCE IDENTIFICATION

CAS-NUMBER 7697-37-2

SUBSTANCE: NITRIC ACID, FUMING

TRADE NAMES/SYNONYMS:

NITRIC ACID, RED FUMING; NITROUS FUMES; RFNA; RED FUMING NITRIC ACID;
 STCC 4918529; UN 2032; A-202; OHS16540

CHEMICAL FAMILY:
 INORGANIC ACID

MOLECULAR FORMULA: H-N-O3 AND N-O2

MOLECULAR WEIGHT: 63.02

CERCLA RATINGS (SCALE 0-3): HEALTH=3 FIRE=0 REACTIVITY=1 PERSISTENCE=0
 NFPA RATINGS (SCALE 0-4): HEALTH=3 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: NITRIC ACID PERCENT: >90.0
 CAS# 7697-37-2

COMPONENT: NITROGEN DIOXIDE PERCENT: 7.5-12.7
 CAS# 10102-44-0

OTHER CONTAMINANTS: FORMALDEHYDE AND OTHER ORGANIC REDUCING AGENTS

EXPOSURE LIMITS:

NITRIC ACID:

2 PPM (5 MG/M3) OSHA TWA; 4 PPM (10 MG/M3) OSHA STEL
 2 PPM (5 MG/M3) ACGIH TWA; 4 PPM (10 MG/M3) ACGIH STEL
 2 PPM (5 MG/M3) NIOSH RECOMMENDED TWA;
 4 PPM (10 MG/M3) NIOSH RECOMMENDED STEL
 10 PPM (25 MG/M3) DFG MAK TWA;
 20 PPM (50 MG/M3) DFG MAK 5 MINUTE PEAK, MOMENTARY VALUE, 8 TIMES/SHIFT

MEASUREMENT METHOD: SILICA GEL TUBE; SODIUM BICARBONATE/SODIUM CARBONATE;
 ION CHROMATOGRAPHY; (NIOSH VOL. III # 7903, INORGANIC ACIDS).

1000 POUNDS SARA SECTION 302 THRESHOLD PLANNING QUANTITY

1000 POUNDS SARA SECTION 304 REPORTABLE QUANTITY

1000 POUNDS CERCLA SECTION 103 REPORTABLE QUANTITY

SUBJECT TO SARA SECTION 313 ANNUAL TOXIC CHEMICAL RELEASE REPORTING

PHYSICAL DATA

DESCRIPTION: YELLOW TO BROWNISH-RED, CLEAR LIQUID WITH SUFFOCATING FUMES.
BOILING POINT: 181 F (83 C) MELTING POINT: -44 F (-42 C)
SPECIFIC GRAVITY: 1.526-1.544 VAPOR PRESSURE: 62 MMHG @ 25 C
EVAPORATION RATE: NOT AVAILABLE SOLUBILITY IN WATER: MISCIBLE
ODOR THRESHOLD: <5.0 PPM VAPOR DENSITY: 2.2
SOLVENT SOLUBILITY: ETHER

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
NEGLIGIBLE FIRE HAZARD WHEN EXPOSED TO HEAT OR FLAME.

OXIDIZER: OXIDIZERS DECOMPOSE, ESPECIALLY WHEN HEATED, TO YIELD OXYGEN OR OTHER GASES WHICH WILL INCREASE THE BURNING RATE OF COMBUSTIBLE MATTER. CONTACT WITH EASILY OXIDIZABLE, ORGANIC, OR OTHER COMBUSTIBLE MATERIALS MAY RESULT IN IGNITION, VIOLENT COMBUSTION OR EXPLOSION.

FIREFIGHTING MEDIA:
WATER, DRY CHEMICAL OR SODA ASH
(1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5).

FOR LARGER FIRES, FLOOD AREA WITH WATER FROM A DISTANCE
(1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5).

FIREFIGHTING:
MOVE CONTAINER FROM FIRE AREA IF YOU CAN DO IT WITHOUT RISK. APPLY COOLING WATER TO SIDES OF CONTAINERS THAT ARE EXPOSED TO FLAMES UNTIL WELL AFTER FIRE IS OUT. STAY AWAY FROM ENDS OF TANKS. FOR MASSIVE FIRE IN CARGO AREA, USE UNMANNED HOSE HOLDER OR MONITOR NOZZLES; IF THIS IS IMPOSSIBLE, WITHDRAW FROM AREA AND LET FIRE BURN (1990 EMERGENCY RESPONSE GUIDEBOOK, DOT P 5800.5, GUIDE PAGE 44).

FLOOD WITH WATER. COOL CONTAINERS WITH FLOODING AMOUNTS OF WATER APPLIED FROM AS FAR A DISTANCE AS POSSIBLE. KEEP UPWIND. IF FIRE IS UNCONTROLLABLE, EVACUATE TO A RADIUS OF 2500 FEET.

TRANSPORTATION DATA

DEPARTMENT OF TRANSPORTATION HAZARD CLASSIFICATION 49 CFR 172.101:
OXIDIZER

DEPARTMENT OF TRANSPORTATION LABELING REQUIREMENTS 49 CFR 172.101 AND
SUBPART E:
OXIDIZER AND POISON

DEPARTMENT OF TRANSPORTATION PACKAGING REQUIREMENTS: 49 CFR 173.268
EXCEPTIONS: NONE

TOXICITY

NITRIC ACID, FUMING:

67 PPM(NO₂)/4 HOURS INHALATION-RAT LC50; CARCINOGEN STATUS: NONE.

NITRIC ACID, FUMING IS TOXIC AND IS A SEVERE SKIN, EYE AND MUCOUS MEMBRANE IRRITANT.

NITROGEN DIOXIDE:

200 PPM/1 MINUTE INHALATION-HUMAN LC50; 90 PPM/40 MINUTES INHALATION-MAN TCLO;
6200 PPB/10 MINUTES INHALATION-MAN TCLO; 88 PPM/4 HOURS INHALATION-RAT LC50;
1000 PPM/10 MINUTES INHALATION-MOUSE LC50; 123 MG/M³ INHALATION-DOG LC50;
315 PPM/15 MINUTES INHALATION-RABBIT LC50; 30 PPM/1 HOUR INHALATION-GUINEA PIG LC50;
MUTAGENIC DATA (RTECS); REPRODUCTIVE EFFECTS DATA (RTECS); CARCINOGEN STATUS: NONE.

NITROGEN DIOXIDE IS TOXIC AND IS A SEVERE EYE, SKIN, AND MUCOUS MEMBRANE IRRITANT. POISONING MAY AFFECT THE RESPIRATORY SYSTEM, BLOOD, AND CENTRAL NERVOUS SYSTEM.

HEALTH EFFECTS AND FIRST AID

INHALATION:

NITRIC ACID, FUMING:

CORROSIVE/TOXIC. 100 PPM IMMEDIATELY DANGEROUS TO LIFE OR HEALTH.

ACUTE EXPOSURE- MAY CAUSE COUGHING, HEADACHE, DIZZINESS, AND WEAKNESS.

DELAYED SYMPTOMS MAY INCLUDE DRYNESS OF THE THROAT AND NOSE, CHEST PAIN OR TIGHTNESS, DYSPNEA, FROTHY SPUTUM, HYPOTENSION AND CYANOSIS FOLLOWED BY PNEUMONITIS AND PULMONARY EDEMA, WHICH MAY BE FATAL. IF PATIENT RECOVERS, SCAR TISSUE MAY CAUSE STRICTURE OF THE PYLORUS OR ESOPHAGUS.

CHRONIC EXPOSURE- REPEATED OR PROLONGED EXPOSURE MAY CAUSE DENTAL EROSION FOLLOWED BY JAW NECROSIS, CHRONIC COUGH AND BRONCHITIS OR CHEMICAL PNEUMONITIS AND GASTROINTESTINAL DISTURBANCES.

NITROGEN DIOXIDE:

CORROSIVE/TOXIC. 50 PPM IMMEDIATELY DANGEROUS TO LIFE OR HEALTH.

ACUTE EXPOSURE- USUALLY NO SYMPTOMS OCCUR AT THE TIME OF EXPOSURE, WITH THE EXCEPTION OF A SLIGHT COUGH AND PERHAPS FATIGUE AND NAUSEA. EXPOSURE TO LOW CONCENTRATIONS, BELOW 50 PPM, MAY RESULT IN IMPAIRED PULMONARY DEFENSE MECHANISMS. ONLY VERY CONCENTRATED FUMES, ABOVE 100 PPM, MAY PRODUCE PROMPT COUGHING, CHOKING, HEADACHE, DIZZINESS, NAUSEA, ABDOMINAL PAIN, AND DYSPNEA. A SYMPTOM-FREE LATENT PERIOD MAY FOLLOW EXPOSURE LASTING 5-72 HOURS. FATIGUE, UNEASINESS, RESTLESSNESS, COUGH, HYPERPNEA, AND DYSPNEA MAY APPEAR GRADUALLY. INCREASINGLY RAPID AND SHALLOW RESPIRATIONS, MILD OR VIOLENT COUGHING WITH FROTHY EXPECTORATIONS, CYANOSIS, POSSIBLE FORMATION OF METHEMOGLOBIN, AND PHYSICAL SIGNS OF PULMONARY EDEMA MAY OCCUR.

ANXIETY, MENTAL CONFUSION, LETHARGY, AND FINALLY LOSS OF CONSCIOUSNESS MAY RESULT. THE CIRCULATORY SYSTEM MAY BE AFFECTION AS NOTED BY A WEAK, RAPID PULSE, DILATED HEART, VENOUS CONGESTION, INTENSE CYANOSIS, AND SEVERE HEMOCOCONCENTRATION. CIRCULATORY COLLAPSE MAY OCCUR BUT IS SECONDARY TO ANOXIA AND HEMOCOCONCENTRATION. DEATH COMMONLY OCCURS WITHIN A FEW HOURS AFTER THE FIRST EVIDENCE OF PULMONARY EDEMA AND IS DUE TO ASPHYXIA. A SECOND ACUTE PHASE SOMETIMES FOLLOWS THE INITIAL PULMONARY REACTION AFTER A LATENT PERIOD OF SEVERAL WEEKS. SIGNS MAY INCLUDE FEVER, CHILLS, COUGH, DYSPNEA, TACHYPNEA, TACHYCARDIA, AND CYANOSIS. THE RELAPSE MAY BE ABRUPT AND FULMINATING, LEADING EITHER TO DEATH OR A SLOW CONVALESCENCE, WHICH MAY BE COMPLICATED BY INFECTIOUS BRONCHITIS, BRONCHIOLITIS OBLITERANS, PNEUMONIA, AND GENERAL ASTHENIA. ONE STUDY WITH RATS INDICATED THAT EXERTION MAY POTENTIATE THE TOXIC EFFECTS OF NITROGEN DIOXIDE.

CHRONIC EXPOSURE- PROLONGED EXPOSURE TO LOW CONCENTRATIONS, INSUFFICIENT TO CAUSE PULMONARY EDEMA, MAY RESULT IN CHRONIC IRRITATION OF THE RESPIRATORY TRACT, WITH HEADACHE, DIZZINESS, ULCERS OF THE NOSE AND MOUTH, MOIST RALES AND WHEEZES, SPORADIC COUGH WITH MUCOPURULENT EXPECTORATION, ANOREXIA, DYSEPSIA, DENTAL EROSION, INSOMNIA, GRADUAL LOSS OF STRENGTH, DYSPNEA UPON EXERTION, CHRONIC BRONCHITIS, AND EMPHYSEMATOUS LESIONS. EFFECTS ON FERTILITY, EMBRYO, AND NEWBORN HAVE BEEN REPORTED WHEN FEMALE RATS WERE CHRONICALLY EXPOSED PRIOR TO MATING. EFFECTS ON THE NEWBORNS HAVE ALSO BEEN REPORTED FROM CHRONIC EXPOSURE DURING PREGNANCY IN RATS.

FIRST AID- REMOVE FROM EXPOSURE AREA TO FRESH AIR IMMEDIATELY. IF BREATHING HAS STOPPED, GIVE ARTIFICIAL RESPIRATION. MAINTAIN AIRWAY AND BLOOD PRESSURE AND ADMINISTER OXYGEN IF AVAILABLE. KEEP AFFECTION PERSON WARM AND AT REST. TREAT SYMPTOMATICALLY AND SUPPORTIVELY. ADMINISTRATION OF OXYGEN SHOULD BE PERFORMED BY QUALIFIED PERSONNEL. GET MEDICAL ATTENTION IMMEDIATELY.

SKIN CONTACT:

NITRIC ACID, FUMING:
CORROSIVE.

ACUTE EXPOSURE- DIRECT CONTACT WITH LIQUID OR CONCENTRATED VAPOR CAUSES IMMEDIATE SEVERE AND PENETRATING BURNS, STAINING THE SKIN YELLOW OR YELLOWISH-BROWN. DILUTE SOLUTIONS PRODUCE MILD IRRITATION AND HARDEN THE SKIN WITHOUT DESTROYING IT.

CHRONIC EXPOSURE- DEPENDING ON CONCENTRATION AND DURATION OF EXPOSURE, REPEATED OR PROLONGED EXPOSURE MAY CAUSE SYMPTOMS AS THOSE OF ACUTE EXPOSURE.

NITROGEN DIOXIDE:

CORROSIVE.

ACUTE EXPOSURE- DIRECT CONTACT WITH LIQUID MAY CAUSE SEVERE IRRITATION, PAIN, YELLOW-BROWN DISCOLORATION, NECROSIS, FROSTBITE, AND POSSIBLE BURNS EITHER BY THE VAPORS OR RAPID EVAPORATION OF THE LIQUID.

CHRONIC EXPOSURE- EFFECTS DEPEND ON CONCENTRATION AND DURATION OF EXPOSURE. REPEATED OR PROLONGED CONTACT WITH CORROSIVE SUBSTANCES MAY RESULT IN DERMATITIS OR EFFECTS SIMILAR TO ACUTE EXPOSURE.

FIRST AID- REMOVE CONTAMINATED CLOTHING AND SHOES IMMEDIATELY. WASH AFFECTED AREA WITH SOAP OR MILD DETERGENT AND LARGE AMOUNTS OF WATER UNTIL NO EVIDENCE OF CHEMICAL REMAINS (AT LEAST 15-20 MINUTES). IN CASE OF CHEMICAL BURNS, COVER AREA WITH STERILE, DRY DRESSING. BANDAGE SECURELY, BUT NOT TOO TIGHTLY. GET MEDICAL ATTENTION IMMEDIATELY.

EYE CONTACT:

NITRIC ACID, FUMING:

CORROSIVE.

ACUTE EXPOSURE- DIRECT CONTACT WITH THE LIQUID MAY CAUSE PAIN, PHOTOPHOBIA, TEARING, EDEMA, CORNEAL ULCERATION, SEVERE BURNS, AND NECROSIS OF THE DEEPER TISSUES WITH PERMANENT DAMAGE.

CHRONIC EXPOSURE- DEPENDING ON CONCENTRATION AND DURATION OF CONTACT, REPEATED OR PROLONGED EXPOSURE MAY CAUSE SYMPTOMS AS THOSE OF ACUTE EXPOSURE.

NITROGEN DIOXIDE:

CORROSIVE.

ACUTE EXPOSURE- DIRECT CONTACT WITH THE LIQUID MAY CAUSE SEVERE IRRITATION WITH REDNESS, PAIN, BLURRED VISION, EDEMA OF THE EYELIDS, CORNEAL ULCERATION, POSSIBLE BURNS, AND FROSTBITE EITHER BY THE VAPORS OR RAPID EVAPORATION OF THE LIQUID.

CHRONIC EXPOSURE- EFFECTS DEPEND ON CONCENTRATION AND DURATION OF EXPOSURE. REPEATED OR PROLONGED CONTACT WITH CORROSIVE SUBSTANCES MAY RESULT IN CONJUNCTIVITIS OR EFFECTS AS IN ACUTE EXPOSURE.

FIRST AID- WASH EYES IMMEDIATELY WITH LARGE AMOUNTS OF WATER, OCCASIONALLY LIFTING UPPER AND LOWER LIDS, UNTIL NO EVIDENCE OF CHEMICAL REMAINS (AT LEAST 15-20 MINUTES). CONTINUE IRRIGATING WITH NORMAL SALINE UNTIL THE PH HAS RETURNED TO NORMAL (30-60 MINUTES). COVER WITH STERILE BANDAGES. GET MEDICAL ATTENTION IMMEDIATELY.

INGESTION:

NITRIC ACID, FUMING:

CORROSIVE.

ACUTE EXPOSURE- IMMEDIATE PAIN IN THE MOUTH, THROAT, AND STOMACH MAY BE FOLLOWED BY NAUSEA, VOMITING, DIARRHEA, HEMATEMESIS, HEMOPTYSIS, HYPOTENSION, NEPHRITIS, ALBUMINURIA, OLIGURIA, ANURIA, HEMATURIA, AND POSSIBLY CIRCULATORY COLLAPSE. ASPHYXIA IS POSSIBLE. BURNS OF THE GASTROINTESTINAL TRACT MAY BE SEVERE ENOUGH TO CAUSE PERFORATION OF THE ESOPHAGUS AND STOMACH WHICH MAY BE FOLLOWED BY MEDIASTINITIS OR PERITONITIS, INDICATED BY FEVER.

CHRONIC EXPOSURE- NO DATA AVAILABLE.

NITROGEN DIOXIDE:

ACUTE EXPOSURE- INGESTION OF THE LIQUID MAY CAUSE AN ACID TASTE, NAUSEA, VOMITING, ABDOMINAL PAIN, AND FROSTBITE DAMAGE OF THE LIPS, MOUTH, AND MUCOUS MEMBRANES.

CHRONIC EXPOSURE- NO DATA AVAILABLE.

FIRST AID: DO NOT USE GASTRIC LAVAGE OR INDUCE VOMITING. DILUTE THE SUBSTANCE IMMEDIATELY WITH LARGE AMOUNTS OF MILK OR WATER. INGESTED ACIDS SHOULD BE DILUTED APPROXIMATELY 100 TIMES TO RENDER IT HARMLESS TO TISSUE. TREAT ASPHYXIA FROM GLOTTAL EDEMA BY MAINTAINING AIRWAY. TREAT SHOCK. (DREISBACH,

HANDBOOK OF POISONING, 11TH EDITION). TREATMENT MUST BE ADMINISTERED BY QUALIFIED MEDICAL PERSONNEL. GET MEDICAL ATTENTION IMMEDIATELY.

ANTIDOTE:

NO SPECIFIC ANTIDOTE. TREAT SYMPTOMATICALLY AND SUPPORTIVELY.

REACTIVITY

REACTIVITY:

REACTS EXOTHERMICALLY WITH WATER.

INCOMPATIBILITIES:

NITRIC ACID:

ACETIC ACID: EXPLOSIVE REACTION IF NOT KEPT COLD.

ACETIC ACID AND ACETONE: EXPLOSIVE REACTION.

ACETIC ANHYDRIDE: EXPLOSIVE REACTION IF NOT KEPT COLD.

ACETONE AND SULFURIC ACID: VIOLENT DECOMPOSITION.

ACETONITRILE: EXPLOSIVE REACTION.

ACETYLENE: YIELDS TRINITROMETHANE, WHICH MELTS AT 15 C; LIQUID IS EXPLOSIVE.
ACROLEIN: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

ACRYLONITRILE: EXPLOSIVE REACTION AT 90 C.

ALLYL ALCOHOL: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

ALLYL CHLORIDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

2-AMINOETHANOL: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

2-AMINOTHIAZOLE AND SULFURIC ACID: POSSIBLE EXPLOSIVE REACTION.

AMMONIA (GAS): BURNS IN AN ATMOSPHERE OF NITRIC ACID VAPOR.

AMMONIUM HYDROXIDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

ANILINE: IGNITES SPONTANEOUSLY.

ANION EXCHANGE RESINS: POSSIBLE VIOLENT EXOTHERMIC REACTION.

ANTIMONY: VIOLENT REACTION.

AROMATIC AMINES: POSSIBLE IGNITION REACTION.

ARSINE: EXPLOSIVE REACTION.

BENZENE: EXPLOSIVE REACTION.

BENZOTHIOPHENE DERIVATIVES: FORMATION OF POSSIBLY EXPLOSIVE COMPOUNDS.

BISMUTH (POWDERED): INTENSE EXOTHERMIC REACTION.

BORON: VIOLENT REACTION WITH INCANDESCENCE.

BORON DECAHYDRATE: EXPLOSIVE REACTION.

BORON PHOSPHIDE: IGNITION REACTION WITH POSSIBLE DEFLAGRATION.

BROMINE PENTAFLUORIDE: IGNITION REACTION.

BUTANE THIOL: VIOLENT DECOMPOSITION.

N-BUTYL MERCAPTAN: IGNITION REACTION.

N-BUTYRALDEHYDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

CALCIUM HYPOPHOSPHITE: IGNITION REACTION.

CARBON (PULVERIZED): VIOLENT REACTION.

CELLULOSE: FORMS EASILY COMBUSTIBLE ETHER.

CESIUM CARBIDE: EXPLOSIVE REACTION.

CHLORINE: INCOMPATIBLE.

4-CHLORO-2-NITROANILINE: FORMS EXPLOSIVE COMPOUND.

CHLOROSULFONIC ACID: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

CROTONALDEHYDE: VIOLENT DECOMPOSITION WITH IGNITION.

CRESOL: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.

CUMENE: TEMPERATURE AND PRESSURE INCREASED IN CLOSED CONTAINER.

CUPRIC NITRIDE: EXPLOSIVE REACTION.

CUPROUS NITRIDE: VIOLENT REACTION.
CYANATES: POSSIBLE EXPLOSIVE REACTION.
CYCLIC KETONES: VIOLENT REACTION.
CYCLOHEXYLAMINE: FORMS EXPLOSIVE SOLUTION.
CYCLOHEXANOL: VIOLENT REACTION.
CYCLOHEXANONE: VIOLENT REACTION.
CYCLOPENTADIENE: EXPLOSIVE REACTION.
1,2-DIAMINOETHANE BISTRIMETHYL GOLD: EXPLOSIVE REACTION.
DIBORANE: SPONTANEOUS IGNITION.
DICHLOROMETHANE: FORMS EXPLOSIVE SOLUTION.
DIENE OR ACETYLENE DERIVATIVES: POSSIBLE IGNITION REACTION.
DIETHYL ETHER: INTENSE REACTION.
DIISOPROPYL ETHER: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
DINITROTOLUENE: EXPLOSIVE REACTION.
DIPHENYL DISTIBENE: EXPLOSIVE OXIDATION.
DIPHENYL TINE: IGNITION REACTION.
2,6-DI-T-BUTYL PHENOL: FORMS EXPLOSIVE COMPOUND.
DIVINYL ETHER: POSSIBLE IGNITION REACTION.
EPICHLOROHYDRIN: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
ETHANOL: VIOLENT REACTION.
ETHANOL AND SILVER: FORMS EXPLOSIVE PRODUCTS.
M-ETHYL ANILINE: IGNITION REACTION.
ETHYL PHOSPHINE: IGNITION REACTION.
5-ETHYL-2-PICOLINE: FORMS EXPLOSIVE COMPOUNDS.
5-ETHYL-2-METHYL PYRIDINE: EXPLOSIVE REACTION.
ETHYLENE DIAMINE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
FERROUS OXIDE (POWDERED): INTENSE EXOTHERMIC REACTION.
FLUORINE: POSSIBLE EXPLOSIVE REACTION.POSSIBLE EXPLOSION.
FURFURYL ALCOHOL: IGNITION REACTION.
GERMANIUM: VIOLENT REACTION.
GLYOXAL: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
HALOGEN PHOSPHIDES: IGNITION REACTION.
HYDRAZINE: VIOLENT REACTION.
HYDRAZOIC ACID: ENERGETIC REACTION.
HYDROGEN IODIDE: IGNITION REACTION.
HYDROGEN PEROXIDE AND KETONES: FORMS EXPLOSIVE PRODUCTS.
HYDROGEN PEROXIDE AND MERCURIC OXIDE: FORMS EXPLOSIVE COMPOUNDS.
HYDROGEN PEROXIDE AND THIOUREA: FORMS EXPLOSIVE COMPOUNDS.
HYDROGEN SULFIDE: INCANDESCENT REACTION.
INDANE AND SULFURIC ACID: EXPLOSIVE REACTION.
ISOPRENE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
LACTIC ACID AND HYDROGEN FLUORIDE: POSSIBLE EXPLOSIVE REACTION.
LITHIUM: IGNITION REACTION.
LITHIUM SILICIDE: INCANDESCENT REACTION.
MAGNESIUM: EXPLOSIVE REACTION.
MAGNESIUM PHOSPHIDE: INCANDESCENT REACTION.
MESITYL OXIDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
MESITYLENE: POSSIBLE EXPLOSIVE REACTION.
METALS: VIOLENT REACTION WITH EXPLOSION OR IGNITION.
METAL CARBIDES: EXPLOSIVE OR VIOLENT REACTION.
METAL FERRICYANIDE OR FERROCYANIDE: INCOMPATIBLE.
METAL SALICYLATES: FORMS EXPLOSIVE COMPOUNDS.
METHANOL: MIXTURES OF GREATER THAN 25% ACID MAY DECOMPOSE VIOLENTLY.
4-METHYLCYCLOHEXANONE: EXPLOSIVE REACTION.

2-METHYL-5-ETHYLPYRIDINE: TEMPERATURE/PRESSURE INCREASE IN CLOSED CONTAINER.
NEODYMIUM PHOSPHIDE: VIOLENT REACTION.
NITRO AROMATIC HYDROCARBONS: FORMS HIGHLY EXPLOSIVE PRODUCTS.
NITROBENZENE: EXPLOSIVE REACTION.
NITROBENZENE AND WATER: EXPLOSIVE REACTION.
NITROMETHANE: EXPLOSIVE REACTION.
NON-METAL OXIDES (ARSINE, PHOSPHINE, TETRABORANE)- EXPLOSIVE REACTION.
OLEUM: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
ORGANIC SUBSTANCES AND PERCHLORATES: POSSIBLE EXPLOSION.
ORGANIC SUBSTANCES AND SULFURIC ACID: POSSIBLE EXPLOSION.
PHENYL ACETYLENE AND 1,1-DIMETHYLHYDRAZINE: VIOLENT REACTION.
PHENYL ORTHOPHOSPHORIC ACID DISODIUM SALT: FORMS EXPLOSIVE PRODUCTS.
PHOSPHINE: VIOLENT DECOMPOSITION.
PHOSPHONIUM IODIDE: IGNITION REACTION.
PHOSPHORUS: IGNITION REACTION.
PHOSPHORUS TETRAIODIDE: VIGOROUS REACTION.
PHOSPHORUS TRICHLORIDE: EXPLOSIVE REACTION.
PHTHALIC ACID AND SULFURIC ACID: POSSIBLE EXPLOSIVE REACTION.
PHTHALIC ANHYDRIDE: EXOTHERMIC REACTION AND FORMS EXPLOSIVE PRODUCTS.
POLYALKENES: INTENSE REACTION..
POLYDIBROMOSILANES: EXPLOSIVE REACTION.
POTASSIUM HYPOPHOSPHITE: EXPLOSIVE REACTION.
B-PROPIOLACTONE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
PROPYLENE OXIDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
PYRIDINE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
REDUCING AGENTS: POSSIBLE EXPLOSIVE OR IGNITION REACTION.
RUBIDIUM CARBIDE: EXPLOSIVE REACTION. POSSIBLE IGNITION REACTION.
SELENIUM: INTENSE REACTION.
SELENIUM HYDRIDE: IGNITION OR INCANDESCENT REACTION.
SELENIUM IODOPHOSPHIDE: EXPLOSIVE REACTION.
SILVER AND ETHYL ALCOHOL: EXPLOSIVE REACTION.
SODIUM: SPONTANEOUS IGNITION.
SODIUM AZIDE: ENERGETIC REACTION.
SULFAMIC ACID: VIOLENT REACTION.
STIBENE: EXPLOSIVE REACTION.
SULFUR DIOXIDE: EXPLOSIVE REACTION.
SULFUR HALIDES: VIOLENT REACTION.
SULFURIC ACID: POSSIBLE EXPLOSIVE REACTION.
SULFURIC ACID AND GLYCERIDES: EXPLOSIVE REACTION.
SULFURIC ACID AND TEREPHTHALIC ACID: VIOLENT REACTION.
TERPENES: SPONTANEOUS IGNITION.
TETRABORANE: EXPLOSIVE REACTION.
TETRABORANE DECAHYDRATE: EXPLOSIVE REACTION.
THIOALDEHYDES OR THIOKETONES: VIOLENT REACTION.
THIOCYANATES: EXPLOSIVE REACTION.
THIOCYANIC ACID METAL SALTS: EXPLOSIVE REACTION.
THIOPHENES: EXPLOSIVE REACTION.
TITANIUM: FORMS EXPLOSIVE COMPOUND.
TITANIUM ALLOY: POSSIBLE EXPLOSIVE REACTION.
TITANIUM-MAGNESIUM ALLOY: POSSIBLE EXPLOSION ON IMPACT.
TOLUENE: INTENSE OR EXPLOSIVE REACTION.
TOLUENE AND SULFURIC ACID: VIOLENT DECOMPOSITION.
TOLIDENE: IGNITION REACTION.
TRIAZINE: EXPLOSIVE REACTION.

TRICADMIUM DIPHOSPHIDE: EXPLOSIVE REACTION.
TRIETHYLGALLIUM MONOETHYL ETHER COMPLEX: IGNITION REACTION.
TRIMETHYLTRIOXANE: INTENSE REACTION.
TRITHIOACETONE: EXPLOSIVE REACTION.
UNSYMMETRICAL DIMETHYL HYDRAZINE: EXPLOSIVE REACTION.
URANIUM: EXPLOSIVE REACTION.
URANIUM ALLOY: VIOLENT REACTION.
URANIUM-NEODYMIUM ALLOY: EXPLOSIVE REACTION.
URANIUM-NEODYMIUM-ZIRCONIUM ALLOY: EXPLOSIVE REACTION.
VINYL ACETATE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
VINYLDENE CHLORIDE: TEMPERATURE AND PRESSURE INCREASE IN CLOSED CONTAINER.
P-XYLENE- INTENSE REACTION IN PRESENCE OF SULFURIC ACID.
ZINC- INCANDESCENT REACTION.
ZIRCONIUM-URANIUM ALLOYS: EXPLOSIVE REACTION.

NITROGEN DIOXIDE (NITROGEN TETROXIDE):
ACETIC ANHYDRIDE: VIOLENT EXPLOSION.
ACETONITRILE AND INDIUM: POSSIBLE EXPLOSION.
ALCOHOLS: POSSIBLE EXPLOSION.
ALUMINUM POWDER: POSSIBLE IGNITION.
AMMONIA: EXPLOSIVE REACTION.
BARIUM OXIDE: INTENSE REACTION AT 200 C.
BORON TRICHLORIDE: INTERACTION IS ENERGETIC.
CALCIUM: EXPLOSIVE INTERACTION.
CARBON DICHLORIDE: FORMATION OF EXPLOSIVE MIXTURE.
CARBON DISULFIDE: FIRE AND EXPLOSION HAZARD.
CARBONYLMETALS: COMBINATION IS HYPERGOLIC.
CESIUM ACETYLENE CARBIDE: IGNITION AT 100 C.
CHLOROFORM: EXPLOSION ON IMPACT.
CELLULOSE AND MAGNESIUM PERCHLORATE: POSSIBLE EXPLOSION.
COMBUSTIBLE MATERIALS: FIRE AND EXPLOSION HAZARD.
CYCLOALKENES AND OXYGEN: FORMATION OF EXPLOSIVE COMPOUND.
CYCLOHEXANE: VIOLENT REACTION.
1,2-DICHLOROETHANE: FORMATION OF EXPLOSIVE MIXTURE.
DICHLOROETHYLENE: FORMATION OF EXPLOSIVE COMPOUND.
DIFLUOROTRIFLUOROMETHYLPHOSPHINE: POSSIBLE IGNITION.
DIMETHYL SULFOXIDE: EXPLOSIVE REACTION.
ETHYLENE: FORMATION OF UNSTABLE COMPOUND.
FLUORINE: POSSIBLE IGNITION.
FORMALDEHYDE: POSSIBLE EXPLOSION.
FUELS: POSSIBLE IGNITION.
HALOCARBONS: FORMATION OF EXPLOSIVE COMPOUND.
HETEROCYCLIC BASES: VIOLENT REACTION.
HYDRAZINE DERIVATIVES: FORMATION OF EXPLOSIVE MIXTURE.
HYDROCARBONS: FORMATION OF EXPLOSIVE PRODUCT.
HYDROGEN AND OXYGEN: FORMATION OF EXPLOSIVE MIXTURE.
IRON (REDUCED): DECOMPOSES WITH INCANDESCENCE.
IRON OXIDE: INCANDESCENT REACTION BY HEATING.
ISOPROPYL NITRITE AND PROPYL NITRITE: POSSIBLE EXPLOSION.
MAGNESIUM: BURNS VIGOROUSLY.
MANGANESE: POSSIBLE IGNITION.
METALS: POSSIBLE IGNITION.
METAL ACETYLIDES: POSSIBLE IGNITION.
METAL CARBOYLS: VIOLENT REACTION.

METHYLENE CHLORIDE: FORMATION OF EXPLOSIVE MIXTURE.
NITROANILINE: POSSIBLE IGNITION.
NITROAROMATICS: POSSIBLE EXPLOSION.
NITROBENZENE: FORMATION OF EXPLOSIVE MIXTURE.
NITROGEN TRICHLORIDES: POSSIBLE EXPLOSION.
OLEFINS: FORMATION OF EXPLOSIVE PRODUCT.
OXIDIZERS (STRONG): REACTS.
OZONE: EXPLOSIVE REACTION.
PETROLEUM: VIOLENT REACTION.
PHOSPHAM: POSSIBLE IGNITION.
PHOSPHINE: POSSIBLE IGNITION.
PHOSPHORUS: VIOLENT COMBUSTION.
PHOSPHORUS TRICHLORIDE: POSSIBLE EXPLOSION.
PHTHALIC ANHYDRIDE AND SULFURIC ACID: EXPLOSIVE DECOMPOSITION.
PLASTICS, RUBBER, COATINGS: MAY BE ATTACKED.
POTASSIUM: POSSIBLE IGNITION.
PROPYLENE: POSSIBLE EXPLOSION.
REDUCING AGENTS: REACTS VIOLENTLY.
SODIUM (GASEOUS): REACTS WITH MARKED LUMINESCENCE AT 260 C.
SODIUM AMIDE: VIOLENT REACTION.
STEEL: CORROSIVE WHEN WET.
SULFUR: VIOLENT COMBUSTION.
SULFURYL CHLORIDE: EXPLOSIVE REACTION.
TETRACARBONYLNICKEL: VIOLENT REACTION.
TETRACHLOROETHANE: FORMATION OF EXPLOSIVE COMPOUND.
TETRACHLOROETHYLENE: FORMATION OF EXPLOSIVE COMPOUND.
TETRAMETHYLTIN: INTERACTION IS EXPLOSIVELY VIOLENT EVEN AT -80 C.
TOLUENE: VIOLENT REACTION.
TRICHLOROETHANE: FORMATION OF EXPLOSIVE COMPOUND.
TRICHLOROETHYLENE: FORMATION OF EXPLOSIVE COMPOUND.
TRIETHYLAMINE: FORMATION OF EXPLOSIVE COMPOUND.
TRIETHYLMONIUM NITRATE: FORMATION OF HEAT-SENSITIVE EXPLOSIVE COMPOUND.
TUNGSTEN CARBIDE: BURNS WITH INCANDESCENCE.
VINYL CHLORIDE: POSSIBLE EXPLOSION.

DECOMPOSITION:

DECOMPOSES ON EXPOSURE TO AIR OR ORGANIC MATTER, OR WITH HEAT, TO RELEASE HIGHLY TOXIC FUMES OF OXIDES OF NITROGEN.

POLYMERIZATION:

HAZARDOUS POLYMERIZATION HAS NOT BEEN REPORTED TO OCCUR UNDER NORMAL TEMPERATURES AND PRESSURES.

STORAGE AND DISPOSAL

OBSERVE ALL FEDERAL, STATE AND LOCAL REGULATIONS WHEN STORING OR DISPOSING OF THIS SUBSTANCE. FOR ASSISTANCE, CONTACT THE DISTRICT DIRECTOR OF THE ENVIRONMENTAL PROTECTION AGENCY.

STORAGE

THRESHOLD PLANNING QUANTITY (TPQ):

THE SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT (SARA) SECTION 302 REQUIRES THAT EACH FACILITY WHERE ANY EXTREMELY HAZARDOUS SUBSTANCE IS PRESENT IN A QUANTITY EQUAL TO OR GREATER THAN THE TPD ESTABLISHED FOR THAT SUBSTANCE NOTIFY THE STATE EMERGENCY RESPONSE COMMISSION FOR THE STATE IN WHICH IT IS LOCATED. SECTION 303 OF SARA REQUIRES THESE FACILITIES TO PARTICIPATE IN LOCAL EMERGENCY RESPONSE PLANNING (40 CFR 355.30).

CONDITIONS TO AVOID

MAY IGNITE OTHER COMBUSTIBLE MATERIALS (WOOD, PAPER, OIL, ETC.). REACTS VIOLENTLY WITH WATER AND FUELS. FLAMMABLE, POISONOUS GASES MAY ACCUMULATE IN TANKS AND HOPPER CARS. RUNOFF TO SEWER MAY CREATE FIRE OR EXPLOSION HAZARD.

CONSULT NFPA PUBLICATION 43A, STORAGE OF LIQUID AND SOLID OXIDIZING MATERIALS, FOR STORAGE REQUIREMENTS.

SPILL AND LEAK PROCEDURES

SOIL SPILL:

DIG A HOLDING AREA SUCH AS A PIT, POND OR LAGOON TO CONTAIN SPILL AND DIKE SURFACE FLOW USING BARRIER OF SOIL, SANDBAGS, FOAMED POLYURETHANE OR FOAMED CONCRETE. ABSORB LIQUID MASS WITH FLY ASH OR CEMENT POWDER.

NEUTRALIZE SPILL WITH SLAKED LIME, SODIUM BICARBONATE OR CRUSHED LIMESTONE.

AIR SPILL:

APPLY WATER SPRAY TO KNOCK DOWN AND REDUCE VAPORS. KNOCK-DOWN WATER IS CORROSIVE AND TOXIC AND SHOULD BE DIKED FOR CONTAINMENT AND LATER DISPOSAL.

WATER SPILL:

ADD SUITABLE AGENT TO NEUTRALIZE SPILLED MATERIAL TO PH-7.

OCCUPATIONAL SPILL:

KEEP COMBUSTIBLES (WOOD, PAPER, OIL, ETC.) AWAY FROM SPILLED MATERIAL. DO NOT TOUCH SPILLED MATERIAL. STOP LEAK IF YOU CAN DO IT WITHOUT RISK. USE WATER SPRAY TO REDUCE VAPORS. DO NOT GET WATER INSIDE CONTAINER. FOR SMALL SPILLS, FLUSH AREA WITH FLOODING AMOUNTS OF WATER. FOR LARGER SPILLS, DIKE FAR AHEAD OF SPILL FOR LATER DISPOSAL. KEEP UNNECESSARY PEOPLE AWAY. ISOLATE HAZARD AREA AND DENY ENTRY. VENTILATE CLOSED SPACES BEFORE ENTERING.

REPORTABLE QUANTITY (RQ): 1000 POUNDS

THE SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT (SARA) SECTION 304 REQUIRES THAT A RELEASE EQUAL TO OR GREATER THAN THE REPORTABLE QUANTITY FOR THIS SUBSTANCE BE IMMEDIATELY REPORTED TO THE LOCAL EMERGENCY PLANNING COMMITTEE AND THE STATE EMERGENCY RESPONSE COMMISSION (40 CFR 355.40). IF THE RELEASE OF THIS SUBSTANCE IS REPORTABLE UNDER CERCLA SECTION 103, THE NATIONAL RESPONSE CENTER MUST BE NOTIFIED IMMEDIATELY AT (800) 424-8802 OR (202) 426-2675 IN THE METROPOLITAN WASHINGTON, D.C. AREA (40 CFR 302.6).

PROTECTIVE EQUIPMENT

VENTILATION:

PROVIDE LOCAL EXHAUST OR PROCESS ENCLOSURE VENTILATION TO MEET PUBLISHED EXPOSURE LIMITS.

RESPIRATOR:

THE FOLLOWING RESPIRATORS AND MAXIMUM USE CONCENTRATIONS ARE RECOMMENDATIONS BY THE U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, NIOSH POCKET GUIDE TO CHEMICAL HAZARDS; NIOSH CRITERIA DOCUMENTS OR BY THE U.S. DEPARTMENT OF LABOR, 29 CFR 1910 SUBPART Z.

THE SPECIFIC RESPIRATOR SELECTED MUST BE BASED ON CONTAMINATION LEVELS FOUND IN THE WORK PLACE, MUST NOT EXCEED THE WORKING LIMITS OF THE RESPIRATOR AND BE JOINTLY APPROVED BY THE NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH AND THE MINE SAFETY AND HEALTH ADMINISTRATION (NIOSH-MSHA).

NITRIC ACID:

125 MG/M₃- ANY SUPPLIED-AIR RESPIRATOR OPERATED IN A CONTINUOUS-FLOW MODE.

250 MG/M₃- ANY SELF-CONTAINED BREATHING APPARATUS WITH A FULL FACEPIECE.

ANY SUPPLIED-AIR RESPIRATOR WITH A FULL FACEPIECE.

ANY AIR-PURIFYING FULL FACEPIECE RESPIRATOR (GAS MASK) WITH A CHIN-STYLE OR FRONT- OR BACK-MOUNTED CANISTER PROVIDING PROTECTION AGAINST NITRIC ACID.

ANY CHEMICAL CARTRIDGE RESPIRATOR WITH A FULL FACEPIECE AND CARTRIDGE(S) PROVIDING PROTECTION AGAINST NITRIC ACID.

ESCAPE- ANY AIR-PURIFYING FULL FACEPIECE RESPIRATOR (GAS MASK) WITH A CHIN-STYLE OR FRONT-OR BACK-MOUNTED CANISTER PROVIDING PROTECTION AGAINST NITRIC ACID.

ANY APPROPRIATE ESCAPE-TYPE SELF-CONTAINED BREATHING APPARATUS.

NOTE: ONLY NON-OXIDIZABLE SORBENTS ARE ALLOWED (NOT CHARCOAL).

FOR FIREFIGHTING AND OTHER IMMEDIATELY DANGEROUS TO LIFE OR HEALTH CONDITIONS:

ANY SELF-CONTAINED BREATHING APPARATUS THAT HAS A FULL FACEPIECE AND IS OPERATED IN A PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE.

ANY SUPPLIED-AIR RESPIRATOR THAT HAS A FULL FACEPIECE AND IS OPERATED IN A PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE IN COMBINATION WITH AN AUXILIARY SELF-CONTAINED BREATHING APPARATUS OPERATED IN PRESSURE-DEMAND OR OTHER POSITIVE-PRESSURE MODE.

CLOTHING:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE (IMPERVIOUS) CLOTHING AND EQUIPMENT TO PREVENT ANY POSSIBILITY OF SKIN CONTACT WITH THIS SUBSTANCE.

GLOVES:

EMPLOYEE MUST WEAR APPROPRIATE PROTECTIVE GLOVES TO PREVENT CONTACT WITH THIS SUBSTANCE.

EYE PROTECTION:

EMPLOYEE MUST WEAR SPLASH-PROOF OR DUST-RESISTANT SAFETY GOGGLES AND A FACESHIELD TO PREVENT CONTACT WITH THIS SUBSTANCE.

EMERGENCY WASH FACILITIES:

WHERE THERE IS ANY POSSIBILITY THAT AN EMPLOYEE'S EYES AND/OR SKIN MAY BE EXPOSED TO THIS SUBSTANCE, THE EMPLOYER SHOULD PROVIDE AN EYE WASH FOUNTAIN AND QUICK DRENCH SHOWER WITHIN THE IMMEDIATE WORK AREA FOR EMERGENCY USE.

AUTHORIZED BY- OCCUPATIONAL HEALTH SERVICES, INC.

CREATION DATE: 11/04/85

REVISION DATE: 05/02/91

OHS16540

7697-37-2

NITRIC ACID, FUMING

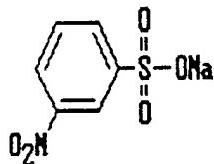
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MATERIAL SAFETY DATA SHEET Version Oct. 1991

Sigma-Aldrich Corporation
1001 West Saint Paul Ave. Milwaukee, WI 53233 USA



IDENTIFICATION

PRODUCT #: 22519-3

CAS #: 127-68-4

MF: C6H5NO5S

NAME: 3-NITROBENZENESULFONIC ACID, SODIUM SALT,
98%

SYNONYMS

SYNOMS LUDIGOL F,60 * M-NITROBENZENESULFONIC ACID SODIUM SALT * NITROBENZEN-M-SULFONAN SODNY (CZECH) * TISKAN (CZECH) *

TOXICITY HAZARDS

TECS NO: DB7195000

BENZENESULFONIC ACID, M-NITRO-, SODIUM SALT

IRRITATION DATA

SKN-RBT 500 MG/24H MLD

85JCAE - , 1053, 86

EYE-BBT 20 MG/24H MOD

85JCAE - , 1053, 86

REVIEWS, STANDARDS, AND REGULATIONS

NEWS, STANDARDS, AND RESOLUTIONS 1983: HZD T1816000: TNF 24: NIS 587; NOS 16; TNE 9386; TFE 1582

EPA TSCA CHEMICAL INVENTORY: JUNE 1990

EPA ISCA CHEMICAL INVENTORY, JUNE 1993
ONLY SELECTED REGISTRY OF TOXIC EFFECTS OF CHEMICAL SUBSTANCES (RTECS)
DATA IS PRESENTED HERE. SEE ACTUAL ENTRY IN RTECS FOR COMPLETE INFORMATION.

• HEALTH HAZARD DATA

ACUTE EFFECTS

MAY BE HARMFUL BY INHALATION, INGESTION, OR SKIN ABSORPTION.
CAUSES EYE AND SKIN IRRITATION.

MATERIAL IS IRRITATING TO MUCOUS MEMBRANES AND UPPER
RESPIRATORY TRACT.

TO THE BEST OF OUR KNOWLEDGE, THE CHEMICAL, PHYSICAL, AND
TOXICOLOGICAL PROPERTIES HAVE NOT BEEN THOROUGHLY INVESTIGATED.

FIRST AID

IN CASE OF CONTACT, IMMEDIATELY FLUSH EYES WITH COPIOUS AMOUNTS OF
WATER FOR AT LEAST 15 MINUTES.

IN CASE OF CONTACT, IMMEDIATELY WASH SKIN WITH SOAP AND COPIOUS
AMOUNTS OF WATER.

IF INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING GIVE ARTIFICIAL
RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.

IF SWALLOWED, WASH OUT MOUTH WITH WATER PROVIDED PERSON IS CONSCIOUS.
CALL A PHYSICIAN.

WASH CONTAMINATED CLOTHING BEFORE REUSE.

----- PHYSICAL DATA -----

APPEARANCE AND ODOR

WHITE TO LIGHT-YELLOW SOLID

----- FIRE AND EXPLOSION HAZARD DATA -----

EXTINGUISHING MEDIA

WATER SPRAY.

CARBON DIOXIDE, DRY CHEMICAL POWDER, ALCOHOL OR POLYMER FOAM.

SPECIAL FIREFIGHTING PROCEDURES

WEAR SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING TO
PREVENT CONTACT WITH SKIN AND EYES.

UNUSUAL FIRE AND EXPLOSIONS HAZARDS

EMITS TOXIC FUMES UNDER FIRE CONDITIONS.

----- REACTIVITY DATA -----

INCOMPATIBILITIES

STRONG OXIDIZING AGENTS

BRASS

CADMIUM

COPPER

NICKEL

MAY DECOMPOSE ON EXPOSURE TO MOIST AIR OR WATER.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS

TOXIC FUMES OF:

CARBON MONOXIDE, CARBON DIOXIDE

NITROGEN OXIDES

SULFUR OXIDES

----- SPILL OR LEAK PROCEDURES -----

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED

WEAR SELF-CONTAINED BREATHING APPARATUS, RUBBER BOOTS AND HEAVY
RUBBER GLOVES.

SWEEP UP, PLACE IN A BAG AND HOLD FOR WASTE DISPOSAL.

AVOID RAISING DUST.

VENTILATE AREA AND WASH SPILL SITE AFTER MATERIAL PICKUP IS COMPLETE.

WASTE DISPOSAL METHOD

DISSOLVE OR MIX THE MATERIAL WITH A COMBUSTIBLE SOLVENT AND BURN IN A
CHEMICAL INCINERATOR EQUIPPED WITH AN AFTERBURNER AND SCRUBBER.

OBSERVE ALL FEDERAL, STATE, AND LOCAL LAWS.

--- PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE ---

CHEMICAL SAFETY GOGGLES.

RUBBER GLOVES.

NIOSH/MSHA-APPROVED RESPIRATOR.

SAFETY SHOWER AND EYE BATH.
MECHANICAL EXHAUST REQUIRED.

AVOID INHALATION.

DO NOT GET IN EYES, ON SKIN, ON CLOTHING.

WASH THOROUGHLY AFTER HANDLING.

IRRITANT.

KEEP TIGHTLY CLOSED.

MOISTURE SENSITIVE

STORE IN A COOL DRY PLACE.

THE ABOVE INFORMATION IS BELIEVED TO BE CORRECT BUT DOES NOT PURPORT TO BE ALL INCLUSIVE AND SHALL BE USED ONLY AS A GUIDE. SIGMA ALDRICH SHALL NOT BE HELD LIABLE FOR ANY DAMAGE RESULTING FROM HANDLING OR FROM CONTACT WITH THE ABOVE PRODUCT. SEE REVERSE SIDE OF INVOICE OR PACKING SLIP FOR ADDITIONAL TERMS AND CONDITIONS OF SALE.

APPENDIX B

**METAL STRIPPERS TESTED TESTED DURING PHASES I-III
OF THE NCYS PROGRAM (FY-89 TO 91)**

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS

AIR FORCE PROCESSES

| <u>Manufacturer</u> | <u>Product</u> | <u>Metal tested</u> | <u>Test conditions</u> |
|------------------------|--------------------------------|---|------------------------|
| Air Force Process C101 | Cyanide Stripping Electrolytic | PHASE I: Cadmium, fuming bronze, indium, lead, nickel, silver, tungs-carb., LAS, SS PHASE II: Copper, nickel | Electrolytic Lab |
| Air Force Process C106 | Cyanide Stripping Immersion | PHASE I: Cadmium, copper fuming bronze, indium, lead, nickel, silver tungs-carb., LAS, SS PHASE II: Nickel, Ni-S | Immersion Lab |
| Air Force Process | Nitric Acid Stripping Solution | PHASE I: Inconel, LAS, SS | Immersion Lab |

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals Tested</u> | <u>Test Conditions</u> |
|---|----------------|---|------------------------|
| Allied-Kelite Div., Witco Corp. 2400 East Devon Ave. Des Plaines, IL 60018 (708) 297-3570 | ARP-60 | PHASE I: Copper, indium, lead, nickel, silver, tin, LAS | Immersion Lab |
| Allied-Kelite Div., Witco Corp. 2400 East Devon Ave. Des Plaines, IL 60018 (708) 297-3570 | ARP-66 | PHASE I: Cadmium, copper, indium, lead, nickel, LAS, SS PHASE II: Copper, fuming bronze, nickel, Ni-S, LAS | Immersion Lab |

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS (Cont'd)

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals tested</u> | <u>Test conditions</u> |
|---|------------------------|--|--------------------------|
| Circuit Chemical Corp. 5129 Industrial Street Maple Plain, MN 55359 (612) 479-2008 | Cirstrip NCN-Cu | PHASE I: Aluminum, chromium, copper, Hastelloy-X, Inconel, indium, lead, nickel, silver, tin, LAS, SS PHASE II: Cadmium, copper, fuming bronze, Ni-S, LAS, SS | Immersion Lab |
| Circuit Chemical Corp. 5129 Industrial Street Maple Plain, MN 55359 (612) 479-2008 | Nicstrip NCN-SCB | PHASE I: Cadmium, copper, fuming bronze, lead, nickel, silver, tin, tungs-carb., LAS, SS | Immersion Lab & Field |
| Electrochemicals 751 Elm Street Youngstown, OH 44502 (216) 746-0517 | Electrostrip S.A. | PHASE I: Cadmium, chromium, indium, lead, nickel, silver, tin, LAS PHASE II: Nickel, LAS, SS | Electrolytic Lab |
| Electrochemicals 751 Elm Street Youngstown, OH 44502 (216) 746-0517 | Nickel-Sol | PHASE I: Aluminum, cadmium, copper, fuming bronze, nickel, tungs-carb., LAS, SS PHASE II: Copper, Inconel, Ni-P, Ni-S, LAS, SS PHASE III: Nickel, LAS, SS | Immersion Lab & Field |
| Enthone, Inc. P.O. Box 1900 New Haven, CT 06508 (203) 934-8611 | Enstrip N-190 N-190 | PHASE III: Inconel, Haynes, nickel, LAS, SS | Immersion Field |
| Frederick Gumm Chemical Co. 538 Forest Street Kearney, NJ 07032 (800) 223-4866 | Clepo 204 | PHASE I: Cadmium, copper, fuming bronze, indium, nickel, silver, tin, tung-carb., LAS, SS PHASE II: Copper, Inconel, Ni-P, Ni-S, LAS, SS PHASE III: Nickel, LAS, SS | Immersion Lab |

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS (Cont'd)

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals tested</u> | <u>Test conditions</u> |
|--|---|---|--|
| Frederick Gumm Chemical Co. 538 Forest Street Kearney, NJ 07032 (800) 223-4866 | Clepo Electrostrip B/C | PHASE I: Cadmium, chromium, copper, indium, lead, nickel, LAS, SS | Electrolytic Lab |
| Kiesow International 201 Greer Drive Mauldin, SC 29662 (803) 963-5808 | Nickel Stripper ST | PHASE I: Cadmium, indium, lead, nickel, silver, LAS, SS PHASE II: Silver, LAS, SS | Electrolytic Lab Electrolytic Lab |
| M&T Harshaw P.O. Box 1104 Rahway, NJ 07065 (201) 499-0200 | Ni-plex 100 Strip | PHASE III: Inconel, Haynes, nickel, LAS, SS | Immersion Field |
| MacDermid, Inc. 526 Huntington Ave. Waterbury, CT 06708 (203) 525-5700 | Metex Electrolytic Rack Stripper SS-10 | PHASE II: Silver, LAS, SS | Electrolytic Lab |
| MacDermid, Inc. 526 Huntington Ave. Waterbury, CT 06708 (203) 525-5700 | Metex Metal Stripper SS-2 | PHASE II: Silver, LAS, SS | Immersion Lab |
| MacDermid, Inc. 526 Huntington Ave. Waterbury, CT 06708 (203) 525-5700 | Metex Nickel Stripper SCB | PHASE I: Cadmium, copper, fuming bronze, indium, nickel, tin, tungs-carb., LAS, SS | Immersion Lab |
| MacDermid, Inc. 526 Huntington Ave. Waterbury, CT 06708 (203) 525-5700 | Metex Nitra- Add 3645 | PHASE II: Silver, LAS, SS | Immersion Lab |
| MacDermid, Inc. 526 Huntington Ave. Waterbury, CT 06708 (203) 525-5700 | Metex Silver Stripper CB | PHASE I: Copper, fuming bronze, nickel, silver, LAS, SS | Immersion Lab |
| McGean-Rohco, Inc. 1250 Terminal Tower Cleveland, Ohio 44113 (216) 441-4900 | Rostrip Electrolytic Stripper 999-SP | PHASE II: Silver, LAS, SS PHASE III: Inconel, Haynes, LAS, SS, silver | Electrolytic Lab Electrolytic Field |

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS (Cont'd)

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals tested</u> | <u>Test conditions</u> |
|---|---------------------------------|---|------------------------|
| Metalline Chemicals Corp. 10620 North Port Washington RD Mequon, WI 53092 (414) 241-3200 | Nickel Stripper 6400 | PHASE I: Cadmium, fuming bronze, nickel, LAS, SS PHASE II: Cadmium, nickel, Immersion LAS | Immersion Lab |
| Metalline Chemicals Corp. 10620 North Port Washington RD Mequon, WI 53092 (414) 241-3200 | Stripper 672 | PHASE I: Cadmium, chromium, copper fuming bronze, lead, nickel, tin, tungs-carb., LAS, SS | Immersion Lab |
| Metalline Chemicals Corp. 10620 North Port Washington RD Mequon, WI 53092 (414) 241-3200 | Zinc Stripper ST-W | PHASE I: Cadmium, chromium, copper, fuming bronze, indium, nickel, tin, tungs- carb., LAS, SS | Immersion Lab |
| Metalx, Inc. Route 10, Box 683 Lenoir, NC 28645 (704) 758-4997 | B-9 Nickel Stripper | PHASE III: Inconel, Haynes, nickel, LAS, SS | Immersion Field |
| Oakite Products, Inc. 50 Valley Road Berkeley Heights, NJ 07922 (201) 464-6900 | Oakite Deoxidizer 104/105 | PHASE II: Silver, LAS, SS | Immersion Lab |
| Oakite Products Inc. 50 Valley Road Berkeley Heights, NJ 07922 (201) 464-6900 | Oakite Stripper Q9 | PHASE II: Silver, LAS, SS | Electrolytic Lab |
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Oxystrip 6000 | PHASE I: Aluminum, cadmium, chromium, fuming bronze, nickel, tungs-carb., LAS, SS | Immersion Lab |

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS (Cont'd)

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals tested</u> | <u>Test conditions</u> |
|---|---|---|--|
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Udylite Immersion Stripper 406 | PHASE I: Cadmium, chromium, copper, fuming bronze, nickel, silver, tungs-carb., LAS, SS | Immersion Lab |
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Udylite Immersion Stripper 460 | PHASE I: Cadmium, copper, fuming bronze, nickel, tin, tungs-carb., LAS, SS | Immersion Lab |
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Udylite Immersion Stripper 460 | PHASE II: Nickel, Ni-S, silver, LAS, SS | Electrolytic Lab |
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Udylite Udystrip 7000 | PHASE I: Cadmium, copper, fuming bronze, nickel, tin, tungs-carb., LAS, SS PHASE II: Ni-S | Electrolytic Lab Electrolytic Lab |
| OMI International Corp. 21441 Hoover Road Warren, MI 48089 (313) 497-9129 | Udylite XPS-306 Immersion Nickel Stripper | PHASE I: Cadmium, copper, fuming bronze, nickel, tungs-carb., LAS, SS PHASE II: Cadmium, nickel, Ni-S, silver, tungs-carb., LAS, SS | Immersion Lab Immersion Lab |
| Patclin Chemical Co., Inc. 66 Alexander Street Yonkers, NY 10701 (914) 476-7000 | Dip N Strip III | PHASE I: Cadmium, copper, fuming bronze, nickel, tungs-carb., LAS, SS | Immersion Lab |
| Patclin Chemical Co., Inc. 66 Alexander Street Yonkers, NY 10701 (914) 476-7000 | Patstrip Ni | PHASE I: Cadmium, chromium, copper, fuming bronze, nickel, silver, tin, tungs-carb., LAS, SS PHASE II: Copper, Ni-P, Ni-S | Immersion Lab Immersion Field |

METAL STRIPPERS TESTED DURING PHASES I-III of NCYS (Cont'd)

COMMERCIALLY AVAILABLE NONCYANIDE STRIPPERS

| <u>Manufacturer</u> | <u>Product</u> | <u>Metals tested</u> | <u>Test conditions</u> |
|---|---------------------------------------|--|--|
| Patclin Chemical Co., Inc. 66 Alexander Street Yonkers, NY 10701 (914) 476-7000 | Patstrip Ni-E | PHASE I: Cadmium, chromium, copper, fuming bronze, nickel, tungs-carb., LAS, SS | Electrolytic Lab |
| Patclin Chemical Co., Inc. 66 Alexander Street Yonkers, NY 10701 (914) 476-7000 | Patstrip #NiX-85 | PHASE I: Aluminum, chromium, copper, fuming bronze, Hasteloy-X, nickel, LAS, SS PHASE II: Copper, Inconel, fuming bronze, nickel, LAS | Immersion Lab Immersion Lab |
| Technic, Inc. One Spectacle Street Cranston, RI 02910 (401) 781-6100 | Cy-less Electrolytic Gold Strip | PHASE II: Silver, LAS, SS PHASE III: Inconel, Haynes, LAS, SS, silver | Electrolytic Lab Electrolytic Field |
| Technic, Inc. One Spectacle Street Cranston, RI 02910 (401) 781-6100 | Non-Cyanide Silver Stripper | PHASE II: Silver, LAS, SS PHASE III: Inconel, Haynes, LAS, SS, silver | Electrolytic Lab Electrolytic Field |

LAS = Low Alloy Steel

SS = Stainless Steel

APPENDIX C

**STRIPPING RATE DATA FOR THE IMPLEMENTATION OF METALX'S
B-9 NICKEL STRIPPER**

| Stripper | Test Date | Coupon Material | Coupon Density # (g/cm ³) | Unmasked Dimensions | | | Air agitation | Temp 140F | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|-----------------|---------------------------------------|---------------------|-------|-------|---------------|-----------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | length | width | thick | | | | | | | | | |
| Implementation of MetalX's B-9 Nickel Stripper Solution Testing Week 2 | | | | | | | | | | | | | | | |
| B-9 Imp | 5-13-91 | Ni-S | 327 | 8.90 | 2.050 | 1.048 | 0.085 | 0.234 | 32.28 | 23.3032 | 22.5541 | 0.7491 | 1.0 | 1.03E+00 | 9.97E-01 |
| B-9 Imp | 5-13-91 | Ni-S | 328 | 8.90 | 2.016 | 1.029 | 0.074 | 0.234 | 30.61 | 18.9932 | 18.3244 | 0.6688 | 1.0 | 9.56E-01 | |
| B-9 Imp | 5-13-91 | Ni-p* | 206 | 8.90 | 2.018 | 1.012 | 0.075 | 0.238 | 30.22 | 18.6902 | 17.7019 | 0.9883 | 2.0 | 7.23E-01 | 6.28E-01 |
| B-9 Imp | 5-13-91 | Ni-p* | 37 | 8.90 | 2.025 | 1.026 | 0.069 | 0.243 | 30.32 | 16.9174 | 16.1885 | 0.7289 | 2.0 | 5.32E-01 | |
| B-9 Imp | 5-13-91 | C4340 | 24 | 7.84 | 2.000 | 1.024 | 0.061 | 0.252 | 29.39 | 15.1744 | 15.1740 | 0.0004 | 24.0 | 2.85E-05 | |
| B-9 Imp | 5-13-91 | D6AC | 110 | 8.20 | 2.027 | 1.006 | 0.067 | 0.250 | 29.65 | 16.4975 | 16.4973 | 0.0002 | 24.0 | 1.35E-05 | |
| B-9 Imp | 5-13-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6574 | 13.6574 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 5-13-91 | 410ss | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0064 | 14.0064 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 5-13-91 | 1-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8506 | 15.8506 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 5-13-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9017 | 34.9015 | 0.0002 | 24.0 | 1.04E-05 | |
| B-9 Imp | 5-13-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0940 | 15.0939 | 0.0001 | 24.0 | 7.29E-06 | |
| Solution Testing Week 3 | | | | | | | | | | | | | | | |
| B-9 Imp | 5-23-91 | Ni-S | 38 | 8.90 | 2.016 | 1.029 | 0.073 | 0.234 | 30.55 | 18.3244 | 17.7615 | 0.5629 | 1.0 | 8.15E-01 | 8.25E-01 |
| B-9 Imp | 5-23-91 | Ni-S | 327 | 8.90 | 2.050 | 1.048 | 0.084 | 0.234 | 32.22 | 22.5544 | 21.9460 | 0.6084 | 1.0 | 8.55E-01 | |
| B-9 Imp | 5-23-91 | Ni-p* | 31 | 8.90 | 2.025 | 1.015 | 0.075 | 0.234 | 30.42 | 18.8964 | 18.3007 | 0.5957 | 1.0 | 8.66E-01 | 7.55E-01 |
| B-9 Imp | 5-23-91 | Ni-p* | 178 | 8.90 | 2.021 | 1.009 | 0.074 | 0.236 | 30.13 | 18.5682 | 18.1298 | 0.4384 | 1.0 | 6.44E-01 | |
| B-9 Imp | 5-23-91 | C4340 | 37 | 7.84 | 2.025 | 1.026 | 0.068 | 0.243 | 30.26 | 15.5781 | 15.5776 | 0.0005 | 101.0 | 8.22E-06 | 5.76E-06 |
| B-9 Imp | 5-23-91 | C4340 | 38 | 7.84 | 2.024 | 1.025 | 0.067 | 0.265 | 30.15 | 15.2912 | 15.291 | 0.0002 | 101.0 | 3.30E-06 | |
| B-9 Imp | 5-23-91 | D6AC | 94 | 8.20 | 2.007 | 1.007 | 0.067 | 0.251 | 29.40 | 17.8384 | 17.8383 | 0.0001 | 101.0 | 1.62E-06 | 1.62E-06 |
| B-9 Imp | 5-23-91 | D6AC | 95 | 8.20 | 2.005 | 1.005 | 0.066 | 0.250 | 29.26 | 18.6211 | 18.6210 | 0.0001 | 101.0 | 1.62E-06 | |
| B-9 Imp | 5-23-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6574 | 13.6577 | -0.0003 | 101.0 | -5.06E-06 | |
| B-9 Imp | 5-23-91 | 410ss | 48 | 7.70 | 2.021 | 1.005 | 0.058 | 0.255 | 28.93 | 14.0064 | 14.0065 | -0.0001 | 101.0 | -1.75E-06 | |
| B-9 Imp | 5-23-91 | 1-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8506 | 15.8510 | -0.0004 | 101.0 | -6.22E-06 | |
| B-9 Imp | 5-23-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9015 | 34.9020 | -0.0005 | 101.0 | -6.18E-06 | |
| B-9 Imp | 5-23-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0939 | 15.0946 | -0.0007 | 101.0 | -1.21E-05 | |
| Solution Testing Week 5 | | | | | | | | | | | | | | | |
| B-9 Imp | 6-6-91 | Ni-S | 226 | 8.90 | 2.031 | 1.027 | 0.076 | 0.243 | 30.85 | 19.7559 | 19.3909 | 0.3650 | 1.0 | 5.23E-01 | |
| B-9 Imp | 6-6-91 | Ni-p* | 126 | 8.90 | 2.024 | 1.013 | 0.076 | 0.234 | 30.41 | 19.0999 | 18.8013 | 0.2986 | 2.0 | 2.17E-01 | 2.12E-01 |
| B-9 Imp | 6-6-91 | Ni-p* | 194 | 8.90 | 2.022 | 1.010 | 0.074 | 0.237 | 30.17 | 18.5539 | 18.2727 | 0.2812 | 2.0 | 2.00E-01 | 3.40E-03 |
| B-9 Imp | 6-6-91 | Ni-p** | 74 | 8.90 | 2.024 | 1.011 | 0.072 | 0.236 | 30.11 | 18.2163 | 18.2111 | 0.0052 | 2.0 | 3.82E-03 | |
| B-9 Imp | 6-6-91 | Ni-p** | 156 | 8.90 | 2.007 | 1.010 | 0.071 | 0.237 | 29.78 | 17.8817 | 17.8777 | 0.0040 | 2.0 | 2.97E-03 | |
| B-9 Imp | 6-6-91 | C4340 | 37 | 7.84 | 2.025 | 1.026 | 0.068 | 0.243 | 30.26 | 15.5776 | 15.5779 | -0.0003 | 24.0 | -2.07E-05 | |
| B-9 Imp | 6-6-91 | D6AC | 95 | 8.20 | 2.005 | 1.005 | 0.066 | 0.250 | 29.26 | 18.6210 | 18.6206 | 0.0004 | 24.0 | 2.73E-05 | |
| B-9 Imp | 6-6-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6577 | 13.6575 | 0.0002 | 24.0 | 1.42E-05 | |
| B-9 Imp | 6-6-91 | 410ss | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0065 | 14.0065 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 6-6-91 | 1-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.267 | 29.15 | 15.8510 | 15.8508 | 0.0002 | 24.0 | 1.31E-05 | |
| B-9 Imp | 6-6-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9020 | 34.9020 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 6-6-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0946 | 15.0946 | -0.0003 | 24.0 | -2.19E-05 | |

| Striper | Test Date | Coupon Material | Coupon Density # (g/cm ³) | Unmasked Dimensions | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) | | |
|---|-----------|-----------------|---------------------------------------|---------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|-----------|-----------------|
| | | | | length | width | thick | | | | | | | | | |
| Solution Testing Week 6 | | | | | | | | | | | | | | | |
| B-9 Imp | 6-12-91 | Ni-S | 226 | 8.90 | 2.029 | 1.026 | 0.075 | 0.242 | 30.74 | 19.3909 | 18.7992 | 0.5917 | 1.0 | 8.52E-01 | |
| B-9 Imp | 6-12-91 | Ni-P* | 126 | 8.90 | 2.023 | 1.012 | 0.073 | 0.233 | 30.20 | 19.0999 | 18.1491 | 0.9508 | 2.0 | 6.96E-01 | 6.96E-01 |
| B-9 Imp | 6-12-91 | Ni-P* | 194 | 8.90 | 2.022 | 1.008 | 0.073 | 0.236 | 30.06 | 18.5539 | 17.6468 | 0.9071 | 2.0 | 6.67E-01 | |
| B-9 Imp | 6-12-91 | Ni-P** | 74 | 8.90 | 2.023 | 1.010 | 0.072 | 0.236 | 30.07 | 18.2163 | 18.1912 | 0.0251 | 2.0 | 1.85E-02 | 2.81E-02 |
| B-9 Imp | 6-12-91 | Ni-P** | 156 | 8.90 | 2.007 | 1.009 | 0.071 | 0.237 | 29.76 | 17.8817 | 17.8309 | 0.0508 | 2.0 | 3.78E-02 | |
| B-9 Imp | 6-12-91 | C4340 | 37 | 7.84 | 2.025 | 1.026 | 0.068 | 0.243 | 30.26 | 15.5779 | 15.5775 | 0.0004 | 24.0 | 2.77E-05 | |
| B-9 Imp | 6-12-91 | D6AC | 95 | 8.20 | 2.005 | 1.005 | 0.066 | 0.250 | 29.26 | 18.6206 | 18.6204 | 0.0002 | 24.0 | 1.37E-05 | |
| B-9 Imp | 6-12-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6575 | 13.6574 | 0.0001 | 24.0 | 7.09E-06 | |
| B-9 Imp | 6-12-91 | 410ss | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0065 | 14.0065 | 0.0000 | 24.0 | 0.00E+00 | |
| B-9 Imp | 6-12-91 | I-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8508 | 15.8509 | -0.0001 | 24.0 | -6.54E-06 | |
| B-9 Imp | 6-12-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9020 | 34.9019 | -0.001 | 24.0 | 5.21E-06 | |
| B-9 Imp | 6-12-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0949 | 15.0948 | 0.0001 | 24.0 | 7.29E-06 | |
| Solution Testing Week 7 | | | | | | | | | | | | | | | |
| B-9 Imp | 6-20-91 | Ni-S | 39 | 8.90 | 2.029 | 1.026 | 0.075 | 0.242 | 30.74 | 18.7603 | 18.3833 | 0.3770 | 2.0 | 2.71E-01 | |
| B-9 Imp | 6-20-91 | Ni-P Kh | 30 | 8.90 | 2.023 | 1.012 | 0.073 | 0.233 | 30.20 | 18.9326 | 18.1235 | 0.8091 | 2.0 | 5.93E-01 | |
| B-9 Imp | 6-20-91 | Ni-P K | 28 | 8.90 | 2.022 | 1.008 | 0.073 | 0.236 | 30.06 | 18.2388 | 17.9187 | 0.3201 | 2.0 | 2.36E-01 | |
| B-9 Imp | 6-20-91 | Ni-P*** | 15 | 8.90 | 2.007 | 1.009 | 0.071 | 0.237 | 29.76 | 17.0163 | 17.0020 | 0.0143 | 2.0 | 1.06E-02 | |
| B-9 Imp | 6-20-91 | C4340 | 37 | 7.84 | 2.025 | 1.026 | 0.068 | 0.243 | 30.26 | 15.5775 | 14.9732 | 0.6043 | 24.0 | 4.18E-02 | |
| B-9 Imp | 6-20-91 | D6AC | 95 | 8.20 | 2.005 | 1.005 | 0.066 | 0.250 | 29.26 | 18.6204 | 18.2651 | 0.3553 | 24.0 | 2.43E-02 | |
| B-9 Imp | 6-20-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6574 | 13.6573 | 0.0001 | 24.0 | 7.09E-06 | |
| B-9 Imp | 6-20-91 | 410ss | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0065 | 14.0062 | 0.0003 | 24.0 | 2.21E-05 | |
| B-9 Imp | 6-20-91 | I-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8509 | 15.8505 | 0.0004 | 24.0 | 2.62E-05 | |
| B-9 Imp | 6-20-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9019 | 34.9009 | 0.0010 | 24.0 | 5.21E-05 | |
| B-9 Imp | 6-20-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0948 | 15.0938 | 0.0010 | 24.0 | 7.29E-05 | |
| Solution Testing Week 9 (after 2nd addition) | | | | | | | | | | | | | | | |
| B-9 Imp | 7-2-91 | Ni-S | 361 | 8.90 | 2.044 | 1.046 | 0.076 | 0.237 | 31.58 | 21.9214 | 20.7902 | 1.1312 | 2.0 | 7.92E-01 | |
| B-9 Imp | 7-2-91 | Ni-S | 364 | 8.90 | 2.045 | 1.051 | 0.079 | 0.235 | 31.92 | 22.6484 | 21.5590 | 1.0894 | 2.0 | 7.55E-01 | |
| B-9 Imp | 7-2-91 | Ni-P*** | 30 | 8.90 | 2.025 | 1.014 | 0.073 | 0.236 | 30.26 | 18.3899 | 18.3820 | 0.0079 | 2.0 | 5.77E-03 | 8.16E-03 |
| B-9 Imp | 7-2-91 | Ni-P*** | 31 | 8.90 | 2.026 | 1.014 | 0.072 | 0.236 | 30.22 | 18.1723 | 18.1579 | 0.0144 | 2.0 | 1.05E-02 | |
| B-9 Imp | 7-2-91 | Ni-P K | 29 | 8.90 | 2.013 | 1.053 | 0.072 | 0.241 | 31.06 | 18.7383 | 17.8004 | 0.9379 | 2.0 | 6.68E-01 | 6.03E-01 |
| B-9 Imp | 7-2-91 | Ni-P K | 31 | 8.90 | 2.014 | 1.040 | 0.072 | 0.239 | 30.74 | 18.6174 | 17.8691 | 0.7483 | 2.0 | 5.38E-01 | |
| B-9 Imp | 7-2-91 | SN | 39 | 8.90 | 2.028 | 1.025 | 0.075 | 0.242 | 30.70 | 18.3833 | 17.4822 | 0.9011 | 2.0 | 6.49E-01 | |
| B-9 Imp | 7-2-91 | NS | 226 | 8.90 | 2.038 | 1.026 | 0.075 | 0.241 | 30.73 | 18.7992 | 17.7850 | 1.0142 | 2.0 | 7.30E-01 | |
| B-9 Imp | 7-2-91 | C340 | 51 | 7.84 | 2.015 | 1.020 | 0.061 | 0.251 | 29.50 | 15.3667 | 15.3639 | *.0028 | 24.0 | 1.99E-04 | |
| B-9 Imp | 7-2-91 | C4340 | 53 | 7.84 | 2.009 | 1.022 | 0.064 | 0.251 | 29.65 | 15.4304 | 15.4302 | 0.0002 | 24.0 | 1.41E-05 | |
| B-9 Imp | 7-2-91 | D6AC | 24 | 8.20 | 2.005 | 0.964 | 0.085 | 0.250 | 29.28 | 19.8549 | 19.8547 | 0.0002 | 24.0 | 1.37E-05 | |
| B-9 Imp | 7-2-91 | D6AC | 25 | 8.20 | 2.011 | 0.993 | 0.083 | 0.249 | 30.03 | 20.3556 | 20.3556 | 0.0000 | 24.0 | 0.00E+00 | |

| Stripper | Test Date | Coupon Material | Coupon # | Coupon Density (g/cm ³) | Unmasked Dimensions in inches----- | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---------------------------------|-----------|-----------------|----------|-------------------------------------|---------------------------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | | length | width | thick | | | | | | | |
| Solution Testing Week 10 | | | | | | | | | | | | | | |
| B-9 Imp | 7-11-91 | Ni-S | 444 | 8.90 | 2.053 | 1.059 | 0.088 | 0.232 | 32.82 | 24.3718 | 24.0706 | 0.3012 | 2.0 | 2.03E-01 |
| B-9 Imp | 7-11-91 | Ni-S | 563 | 8.90 | 2.080 | 1.049 | 0.093 | 0.231 | 33.24 | 27.1061 | 26.7104 | 0.3957 | 2.0 | 2.63E-01 |
| B-9 Imp | 7-11-91 | Ni-P* | 207 | 8.90 | 2.030 | 1.018 | 0.075 | 0.236 | 30.56 | 18.7840 | 18.5620 | 0.2220 | 2.0 | 1.61E-01 |
| B-9 Imp | 7-11-91 | Ni-P* | 209 | 8.90 | 2.020 | 1.120 | 0.074 | 0.236 | 33.12 | 18.5477 | 18.4095 | 0.1382 | 2.0 | 9.23E-02 |
| B-9 Imp | 7-11-91 | Ni-P K | 32 | 8.90 | 2.013 | 1.035 | 0.072 | 0.243 | 30.57 | 18.3822 | 18.1970 | 0.1852 | 2.0 | 1.34E-01 |
| B-9 Imp | 7-11-91 | Ni-P K | 33 | 8.90 | 2.015 | 1.045 | 0.072 | 0.244 | 30.86 | 18.5109 | 18.3602 | 0.1507 | 2.0 | 1.08E-01 |
| B-9 Imp | 7-11-91 | C4340 | 6 | 7.84 | 2.011 | 1.001 | 0.063 | 0.250 | 29.06 | 15.5559 | 15.5556 | 0.0003 | 24.0 | 2.16E-05 |
| B-9 Imp | 7-11-91 | C4340 | 4 | 7.84 | 2.010 | 1.000 | 0.063 | 0.248 | 29.03 | 15.1843 | 15.1839 | 0.0004 | 24.0 | 2.88E-05 |
| B-9 Imp | 7-11-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6573 | 13.6574 | -0.0001 | 24.0 | -7.09E-06 |
| B-9 Imp | 7-11-91 | 410SS | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0062 | 14.0060 | 0.0002 | 24.0 | 1.47E-05 |
| B-9 Imp | 7-11-91 | I-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8505 | 15.8505 | 0.0000 | 24.0 | 0.00E+00 |
| B-9 Imp | 7-11-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9009 | 34.9011 | -0.0002 | 24.0 | -1.04E-05 |
| B-9 Imp | 7-11-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0938 | 15.0942 | -0.0004 | 24.0 | -2.91E-05 |
| Solution Testing Week 11 | | | | | | | | | | | | | | |
| B-9 Imp | 7-19-91 | Ni-S | 444 | 8.90 | 2.051 | 1.059 | 0.088 | 0.232 | 32.79 | 24.0706 | 23.4637 | 0.6069 | 2.0 | 4.09E-01 |
| B-9 Imp | 7-19-91 | Ni-S | 563 | 8.90 | 2.080 | 1.048 | 0.093 | 0.231 | 33.22 | 26.7104 | 25.9503 | 0.7601 | 2.0 | 5.06E-01 |
| B-9 Imp | 7-19-91 | Ni-P* | 207 | 8.90 | 2.028 | 1.016 | 0.073 | 0.236 | 30.36 | 18.5620 | 18.2255 | 0.3365 | 2.0 | 2.45E-01 |
| B-9 Imp | 7-19-91 | Ni-P* | 209 | 8.90 | 2.018 | 1.010 | 0.073 | 0.236 | 30.06 | 18.4095 | 18.0610 | 0.3485 | 2.0 | 2.51E-01 |
| B-9 Imp | 7-19-91 | Ni-P K | 32 | 8.90 | 2.010 | 1.033 | 0.071 | 0.243 | 30.41 | 18.1970 | 17.7074 | 0.4896 | 2.0 | 3.56E-01 |
| B-9 Imp | 7-19-91 | C4340 | 33 | 8.90 | 2.013 | 1.042 | 0.071 | 0.241 | 30.71 | 18.3602 | 17.8671 | 0.4931 | 2.0 | 3.55E-01 |
| B-9 Imp | 7-19-91 | C4340 | 4 | 7.84 | 2.010 | 1.000 | 0.063 | 0.249 | 29.02 | 15.1839 | 15.1837 | 0.0002 | 27.0 | 1.28E-05 |
| B-9 Imp | 7-19-91 | 3160 | 6 | 7.84 | 2.011 | 1.001 | 0.063 | 0.250 | 29.06 | 15.5556 | 15.5555 | 0.0001 | 27.0 | 6.40E-06 |
| B-9 Imp | 7-19-91 | 3160 | 7 | 8.03 | 2.010 | 1.005 | 0.057 | 0.250 | 28.80 | 13.6574 | 13.6574 | 0.0000 | 27.0 | 0.00E+00 |
| B-9 Imp | 7-19-91 | 410SS | 48 | 7.70 | 2.021 | 1.003 | 0.058 | 0.255 | 28.93 | 14.0060 | 14.0058 | 0.0002 | 27.0 | 1.31E-05 |
| B-9 Imp | 7-19-91 | I-718 | 39 | 8.60 | 2.011 | 1.004 | 0.063 | 0.247 | 29.15 | 15.8505 | 15.8503 | 0.0002 | 27.0 | 1.16E-05 |
| B-9 Imp | 7-19-91 | HA-188 | 43 | 9.70 | 1.987 | 1.005 | 0.125 | 0.249 | 32.49 | 34.9011 | 34.9009 | -0.0002 | 27.0 | 9.25E-06 |
| B-9 Imp | 7-19-91 | 17-4PH | 3 | 7.80 | 2.000 | 1.000 | 0.064 | 0.265 | 28.86 | 15.0938 | 15.0942 | -0.0004 | 27.0 | 1.94E-05 |

| Stripper | Test Date | Coupon Material | Unmasked Dimensions | | | | Coupon Density (g/cm ³) | Length | Width | Thickness | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) |
|---|-----------|-----------------|---------------------|-------|-----------|-------|-------------------------------------|--------|-------|-----------|---------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|
| | | | length | width | thickness | hole | | | | | | | | | | | |
| Metals B-9 Nickel Stripper Implementation Tests - Second Tank prepared by the Batch Method | | | | | | | | | | | | | | | | | |
| 2nd Tank | Temp 144F | pH 10.1 | air agitation | | | | | | | | | | | | | | |
| B-9 Imp2 | 8-12-91 | Ni-S K | 397 | 8.90 | 2.050 | 1.036 | 0.078 | 0.237 | 31.51 | 21.3518 | 20.1782 | 1.1736 | 2.0 | 8.24E-01 | 8.51E-01 | | |
| B-9 Imp2 | 8-12-91 | Ni-S K | 399 | 8.90 | 2.041 | 1.037 | 0.078 | 0.236 | 31.42 | 20.8354 | 19.5875 | 1.2479 | 2.0 | 8.79E-01 | | | |
| B-9 Imp2 | 8-12-91 | Ni-P K | 96 | 8.90 | 2.012 | 1.011 | 0.073 | 0.238 | 29.99 | 18.0417 | 18.0127 | 0.0290 | 2.0 | 2.14E-02 | 1.72E-02 | | |
| B-9 Imp2 | 8-12-91 | Ni-P K | 97 | 8.90 | 2.023 | 1.011 | 0.071 | 0.238 | 30.03 | 17.9241 | 17.9063 | 0.0178 | 2.0 | 1.31E-02 | | | |
| B-9 Imp2 | 8-12-91 | Ni-P K | 2 | 8.90 | 2.014 | 0.986 | 0.091 | 0.240 | 30.40 | 22.1358 | 21.4110 | 0.7248 | 2.0 | 5.27E-01 | 5.34E-01 | | |
| B-9 Imp2 | 8-12-91 | Ni-P K | 3 | 8.90 | 2.000 | 0.998 | 0.090 | 0.242 | 30.46 | 22.0296 | 21.2861 | 0.7435 | 2.0 | 5.40E-01 | | | |
| B-9 Imp2 | 8-12-91 | C4340 | 6 | 7.84 | 2.009 | 0.987 | 0.063 | 0.249 | 28.66 | 15.0230 | 15.0230 | 0.0000 | 24.0 | 0.00E+00 | | | |
| B-9 Imp2 | 8-12-91 | D6AC | 45 | 7.84 | 2.013 | 0.963 | 0.082 | 0.248 | 29.19 | 19.2700 | 19.2698 | 0.0002 | 24.0 | 1.43E-05 | | | |
| B-9 Imp2 | 8-12-91 | 3160 | 49 | 8.03 | 2.002 | 1.007 | 0.067 | 0.249 | 29.34 | 13.7867 | 13.7870 | -0.0003 | 24.0 | -2.09E-05 | | | |
| B-9 Imp2 | 8-12-91 | 410ss | 26 | 7.70 | 2.015 | 1.006 | 0.059 | 0.254 | 28.99 | 13.6996 | 13.6996 | 0.0002 | 24.0 | 1.47E-05 | | | |
| B-9 Imp2 | 8-12-91 | I-718 | 34 | 8.60 | 2.014 | 1.015 | 0.064 | 0.245 | 29.56 | 16.2541 | 16.2543 | -0.0002 | 24.0 | -1.29E-05 | | | |
| B-9 Imp2 | 8-12-91 | HA-188 | 74 | 9.70 | 2.014 | 1.007 | 0.127 | 0.244 | 33.08 | 36.3666 | 36.3670 | -0.0004 | 24.0 | -2.04E-05 | | | |
| B-9 Imp2 | 8-12-91 | 17-4PH | 51 | 7.80 | 2.015 | 1.004 | 0.063 | 0.257 | 29.16 | 15.3700 | 15.3701 | -0.0001 | 24.0 | -7.21E-06 | | | |
| 2nd Tank | Temp 144F | pH 10.1 | air agitation | | | | | | | | | | | | | | |
| B-9 Imp2 | 8-22-91 | Ni-S K | 397 | 8.90 | 2.042 | 1.031 | 0.075 | 0.240 | 31.07 | 20.1789 | 19.1139 | 1.0650 | 2.0 | 7.58E-01 | 8.21E-01 | | |
| B-9 Imp2 | 8-22-91 | Ni-S K | 399 | 8.90 | 2.037 | 1.030 | 0.073 | 0.239 | 30.85 | 19.5880 | 18.3563 | 1.2317 | 2.0 | 8.83E-01 | | | |
| B-9 Imp2 | 8-22-91 | Ni-P K | 2 | 8.90 | 2.012 | 0.984 | 0.087 | 0.243 | 30.07 | 21.4114 | 20.8754 | 0.5360 | 2.0 | 3.94E-01 | 4.00E-01 | | |
| B-9 Imp2 | 8-22-91 | Ni-P K | 3 | 8.90 | 2.007 | 0.988 | 0.085 | 0.244 | 29.84 | 21.2862 | 20.7385 | 0.5477 | 2.0 | 4.06E-01 | | | |
| B-9 Imp2 | 8-22-91 | C4340 | 6 | 7.84 | 2.009 | 0.987 | 0.063 | 0.249 | 28.66 | 15.0229 | 15.0229 | 0.0001 | 24.0 | 7.30E-06 | | | |
| B-9 Imp2 | 8-22-91 | D6AC | 45 | 8.20 | 2.013 | 0.963 | 0.082 | 0.248 | 29.19 | 19.2700 | 19.2696 | 0.0004 | 24.0 | 2.74E-05 | | | |
| B-9 Imp2 | 8-22-91 | 3160 | 49 | 8.03 | 2.002 | 1.007 | 0.067 | 0.249 | 29.34 | 13.7866 | 13.7864 | 0.0002 | 24.0 | 1.39E-05 | | | |
| B-9 Imp2 | 8-22-91 | 410ss | 26 | 7.70 | 2.015 | 1.006 | 0.059 | 0.254 | 28.99 | 13.6989 | 13.6989 | 0.0000 | 24.0 | 0.00E+00 | | | |
| B-9 Imp2 | 8-22-91 | I-718 | 34 | 8.60 | 2.014 | 1.015 | 0.064 | 0.245 | 29.56 | 16.2540 | 16.2540 | 0.0000 | 24.0 | 0.00E+00 | | | |
| B-9 Imp2 | 8-22-91 | HA-188 | 74 | 9.70 | 2.014 | 1.007 | 0.127 | 0.244 | 33.08 | 36.3666 | 36.3665 | 0.0001 | 24.0 | 5.11E-06 | | | |
| B-9 Imp2 | 8-22-91 | 17-4PH | 51 | 7.80 | 2.015 | 1.004 | 0.063 | 0.257 | 29.16 | 15.3699 | 15.3699 | 0.0000 | 24.0 | 0.00E+00 | | | |
| 2nd Tank | Temp 142F | pH 10.0 | air agitation | | | | | | | | | | | | | | |
| B-9 Imp2 | 8-29-91 | Ni-S K | 397 | 8.90 | 2.032 | 1.026 | 0.075 | 0.243 | 30.77 | 19.1139 | 18.0007 | 1.1132 | 2.0 | 8.00E-01 | 8.23E-01 | | |
| B-9 Imp2 | 8-29-91 | Ni-S K | 399 | 8.90 | 2.033 | 1.022 | 0.073 | 0.242 | 30.57 | 18.3563 | 17.1875 | 1.1688 | 2.0 | 8.46E-01 | | | |
| B-9 Imp2 | 8-29-91 | Ni-P K | 2 | 8.90 | 2.008 | 0.983 | 0.087 | 0.247 | 29.96 | 20.8754 | 20.2257 | 0.6497 | 2.0 | 4.80E-01 | 4.70E-01 | | |
| B-9 Imp2 | 8-29-91 | Ni-P K | 3 | 8.90 | 1.994 | 0.978 | 0.085 | 0.247 | 29.52 | 20.7385 | 20.1249 | 0.6136 | 2.0 | 4.60E-01 | | | |
| B-9 Imp2 | 8-29-91 | C4340 | 6 | 7.84 | 2.009 | 0.987 | 0.063 | 0.249 | 28.66 | 15.0228 | 15.0228 | 0.0003 | 24.0 | 2.19E-05 | | | |
| B-9 Imp2 | 8-29-91 | D6AC | 45 | 8.20 | 2.013 | 0.963 | 0.082 | 0.248 | 29.19 | 19.2696 | 19.2687 | 0.0009 | 24.0 | 6.17E-05 | | | |
| B-9 Imp2 | 8-29-91 | 3160 | 49 | 8.03 | 2.002 | 1.007 | 0.067 | 0.249 | 29.34 | 13.7864 | 13.7869 | -0.0005 | 24.0 | -3.48E-05 | | | |
| B-9 Imp2 | 8-29-91 | 410ss | 26 | 7.70 | 2.015 | 1.006 | 0.059 | 0.254 | 28.99 | 13.6989 | 13.6989 | 0.0000 | 24.0 | 0.00E+00 | | | |
| B-9 Imp2 | 8-29-91 | I-718 | 34 | 8.60 | 2.014 | 1.015 | 0.064 | 0.265 | 29.56 | 16.2540 | 16.2541 | -0.0001 | 24.0 | -6.45E-06 | | | |
| B-9 Imp2 | 8-29-91 | HA-188 | 74 | 9.70 | 2.014 | 1.007 | 0.127 | 0.244 | 33.08 | 36.3665 | 36.3665 | 0.0000 | 24.0 | 0.00E+00 | | | |
| B-9 Imp2 | 8-29-91 | 17-4PH | 51 | 7.80 | 2.015 | 1.004 | 0.063 | 0.257 | 29.16 | 15.3699 | 15.3699 | 0.0000 | 24.0 | 0.00E+00 | | | |

| Stripper | Test Date | Coupon Material | Coupon Density # (g/cm3) | Unmasked Dimensions -----in inches----- | | | Surface Area (cm2) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) |
|----------|-----------|-----------------|--------------------------|---|-------|-------|--------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|
| | | | | length | width | thick | | | | | | | |
| 2nd Tank | Temp 143F | pH 10.1 | air agitation | | | | | | | | | | |
| B-9 Imp2 | 9-5-91 | Ni-S K | .42 | 8.90 | 2.046 | 1.047 | 0.074 | 0.246 | 31.47 | 20.0790 | 18.7413 | 1.3377 | 2.0 9.40E-01 |
| B-9 Imp2 | 9-5-91 | Ni-S K | .44 | 8.90 | 2.040 | 1.054 | 0.076 | 0.244 | 31.71 | 20.4069 | 19.1718 | 1.2351 | 2.0 8.62E-01 |
| B-9 Imp2 | 9-5-91 | Ni-P K | .46 | 8.90 | 2.020 | 1.002 | 0.083 | 0.247 | 30.41 | 21.4370 | 20.6648 | 0.7722 | 2.0 5.62E-01 |
| B-9 Imp2 | 9-5-91 | Ni-P K | .50 | 8.90 | 2.020 | 1.008 | 0.082 | 0.241 | 30.54 | 20.3999 | 19.5605 | 0.7394 | 2.0 5.35E-01 |
| B-9 Imp2 | 9-5-91 | D6AC | .98 | 7.84 | 2.029 | 1.012 | 0.080 | 0.254 | 30.59 | 19.5918 | 19.5914 | 0.0004 | 24.0 2.74E-05 |
| B-9 Imp2 | 9-5-91 | C4340 | .37 | 8.20 | 1.975 | 1.027 | 0.061 | 0.253 | 29.12 | 14.9841 | 14.9839 | 0.0002 | 24.0 1.37E-05 |
| 2nd Tank | Temp 144F | pH 10.1 | air agitation | | | | | | | | | | |
| B-9 Imp2 | 9-12-91 | Ni-S K | .40 | 8.90 | 2.020 | 1.050 | 0.074 | 0.242 | 31.20 | 19.0644 | 17.8816 | 1.1828 | 2.0 8.39E-01 |
| B-9 Imp2 | 9-12-91 | Ni-S K | .45 | 8.90 | 2.025 | 1.046 | 0.073 | 0.249 | 31.07 | 19.1582 | 18.1206 | 1.0376 | 2.0 7.39E-01 |
| B-9 Imp2 | 9-12-91 | Ni-P K | .48 | 8.90 | 2.013 | 1.006 | 0.071 | 0.241 | 29.74 | 17.6006 | 16.9439 | 0.6567 | 2.0 4.88E-01 |
| B-9 Imp2 | 9-12-91 | Ni-P K | .49 | 8.90 | 2.015 | 1.009 | 0.085 | 0.242 | 30.67 | 20.6737 | 19.9850 | 0.6887 | 2.0 4.97E-01 |
| B-9 Imp2 | 9-12-91 | C4340 | .38 | 7.84 | 1.998 | 1.025 | 0.061 | 0.249 | 29.27 | 15.0278 | 15.0279 | -0.0001 | 24.0 -7.15E-06 |
| B-9 Imp2 | 9-12-91 | C4340 | .37 | 7.84 | 1.975 | 1.027 | 0.061 | 0.253 | 29.12 | 14.9839 | 14.9835 | 0.0004 | 24.0 2.87E-05 |
| B-9 Imp2 | 9-12-91 | D6AC | .98 | 8.20 | 2.029 | 1.012 | 0.080 | 0.245 | 30.64 | 19.5914 | 19.5914 | 0.0000 | 24.0 0.000E+00 |
| B-9 Imp2 | 9-12-91 | D6AC | .96 | 8.20 | 2.010 | 1.011 | 0.079 | 0.251 | 30.26 | 19.0678 | 19.0677 | 0.0001 | 24.0 6.61E-06 |
| 2nd Tank | Temp 142F | pH 10.1 | air agitation | | | | | | | | | | |
| B-9 Imp2 | 9-18-91 | Ni-S K** | .40 | 8.90 | 2.007 | 1.045 | 0.072 | 0.246 | 30.74 | 17.8816 | 17.8816 | 0.8000 | 2.0 5.76E-01 |
| B-9 Imp2 | 9-18-91 | Ni-S K** | .45 | 8.90 | 2.014 | 1.037 | 0.071 | 0.265 | 30.57 | 18.1206 | 17.3283 | 0.7923 | 2.0 5.75E-01 |
| B-9 Imp2 | 9-18-91 | Ni-P K | .48 | 8.90 | 2.010 | 1.004 | 0.069 | 0.247 | 29.50 | 16.9439 | 16.4218 | 0.5221 | 2.0 3.92E-01 |
| B-9 Imp2 | 9-18-91 | Ni-P K | .49 | 8.90 | 2.012 | 1.004 | 0.082 | 0.247 | 30.29 | 19.9850 | 19.4485 | 0.5365 | 2.0 3.92E-01 |
| B-9 Imp2 | 9-18-91 | C4340 | .38 | 7.84 | 1.998 | 1.025 | 0.061 | 0.249 | 29.27 | 15.0276 | 15.0276 | 0.0000 | 24.0 0.000E+00 |
| B-9 Imp2 | 9-18-91 | C4340 | .37 | 7.84 | 1.975 | 1.027 | 0.061 | 0.253 | 29.12 | 14.9835 | 14.9831 | 0.0004 | 24.0 1.44E-05 |
| B-9 Imp2 | 9-18-91 | D6AC | .98 | 8.20 | 2.029 | 1.012 | 0.080 | 0.245 | 30.64 | 19.5914 | 19.5910 | 0.0004 | 24.0 2.87E-05 |
| B-9 Imp2 | 9-18-91 | D6AC | .96 | 8.20 | 2.010 | 1.011 | 0.079 | 0.251 | 30.26 | 19.0677 | 19.0674 | 0.0003 | 24.0 2.30E-05 |

**Note: above plated coupons had areas stripped to basis metal

The repeat of above test Temp 142F pH 10.0 air agitation
 B-9 Imp2 9-19-91 Ni-S K .39 8.90 2.005 1.008 0.070 0.246 29.60 17.8765 16.8979 0.9786 2.0 7.31E-01
 B-9 Imp2 9-19-91 Ni-S K .582 8.90 2.014 1.037 0.071 0.245 30.57 20.8762 19.8887 0.9855 2.0 7.13E-01
 B-9 Imp2 9-19-91 Ni-P K .10 8.90 2.010 1.004 0.069 0.247 29.50 19.0420 18.3222 0.6098 2.0 4.57E-01
 B-9 Imp2 9-19-91 Ni-P K .15 8.90 2.012 1.004 0.082 0.247 30.29 19.5423 18.9222 0.6201 2.0 4.53E-01

APPENDIX D

**STRIPPING RATE DATA FOR THE IMPLEMENTATION OF McGEAN-ROHCO'S
ROSTRIP ELECTROLYTIC STRIPPER 999-SP
AND THE AF C-101 PROCESS**

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Initial Area hole (cm ²) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|--|-----------|-------------------|-------------------------------------|---------------------|-------|-----------|--------------------------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | length | width | thickness | | | | | | |
| Implementation Testing of McGean-Rohco's Rostrip 999-SP Test Conditions: Ambient Temp. (91F), pH 10.7, air agitation, Ag - 3.0 V, 3.0 Amp; Basis metals - 6.6 V, 17.5 Amp | | | | | | | | | | | | |
| Rostrip 999 | 7-10-91 | Ag w/air | 5 | 10.50 | 1.982 | 0.975 | 0.124 | 0.243 | 31.57 | 37.9968 | 36.8304 | 1.1664 |
| Rostrip 999 | 7-10-91 | Ag no/air | 6 | 10.50 | 1.989 | 1.001 | 0.122 | 0.243 | 32.26 | 39.5144 | 38.1342 | 1.3802 |
| Rostrip 999 | 7-12-91 | C4340 | 10 | 7.84 | 2.007 | 0.986 | 0.062 | 0.249 | 28.55 | 14.9850 | 14.9734 | 0.0116 |
| Rostrip 999 | 7-12-91 | D6AC | 43 | 8.20 | 2.007 | 1.000 | 0.079 | 0.247 | 29.94 | 19.2168 | 19.1968 | 0.0200 |
| Rostrip 999 | 7-12-91 | 316 | 53 | 8.00 | 2.013 | 1.011 | 0.068 | 0.255 | 29.63 | 14.1481 | 14.0016 | 0.1465 |
| Rostrip 999 | 7-12-91 | 410 | 30 | 7.70 | 2.032 | 1.007 | 0.060 | 0.249 | 29.34 | 13.9259 | 13.8970 | 0.0289 |
| Rostrip 999 | 7-12-91 | I-718 | 32 | 8.60 | 2.016 | 1.003 | 0.063 | 0.246 | 29.20 | 16.1471 | 11.3035 | 4.8436 |
| Rostrip 999 | 7-12-91 | HA-188 | 27 | 9.70 | 2.006 | 1.006 | 0.126 | 0.245 | 32.87 | 35.9048 | 30.5266 | 5.3782 |
| Rostrip 999 | 7-12-91 | 17-4PH | 44 | 7.80 | 1.995 | 1.009 | 0.062 | 0.260 | 28.94 | 14.7169 | 14.6308 | 0.0861 |
| Test Conditions: Ambient Temp., pH 10.0, air agitation, Ag - 4.4 V, 6.0 Amp; Basis metals - 7.1 V, 15.7-15.8 Amp | | | | | | | | | | | | |
| Rostrip 999 | 7-25-91 | Ag | 13 | 10.50 | 1.971 | 0.975 | 0.125 | 0.244 | 31.47 | 38.3432 | 36.6293 | 1.7139 |
| Rostrip 999 | 7-25-91 | Ag | 14 | 10.50 | 1.989 | 1.001 | 0.125 | 0.242 | 32.44 | 39.4646 | 37.5509 | 1.9137 |
| Rostrip 999 | 7-25-91 | C4340 | 49 | 7.84 | 2.007 | 1.002 | 0.062 | 0.249 | 29.48 | 15.2632 | 15.2512 | 0.0120 |
| Rostrip 999 | 7-25-91 | D6AC | 18 | 8.20 | 2.008 | 0.998 | 0.079 | 0.253 | 29.87 | 19.2192 | 19.1948 | 0.0244 |
| Rostrip 999 | 7-25-91 | 316 | 36 | 8.00 | 2.011 | 1.005 | 0.068 | 0.251 | 29.46 | 14.0115 | 13.9519 | 0.0596 |
| Rostrip 999 | 7-25-91 | 410 | 17 | 7.70 | 2.008 | 1.005 | 0.059 | 0.256 | 28.86 | 14.1253 | 14.0978 | 0.0275 |
| Rostrip 999 | 7-25-91 | I-718 | 21 | 8.60 | 2.023 | 1.005 | 0.063 | 0.245 | 29.36 | 15.9794 | 12.7282 | 3.2512 |
| Rostrip 999 | 7-25-91 | HA-188 | 79 | 9.70 | 2.003 | 1.012 | 0.127 | 0.245 | 33.05 | 36.2781 | 31.8080 | 4.4701 |
| Rostrip 999 | 7-25-91 | 17-4PH | 36 | 7.80 | 2.003 | 1.010 | 0.061 | 0.258 | 29.03 | 14.6175 | 14.5612 | 0.0563 |
| Test Conditions: Ambient Temp., pH 11.5, air agitation, Ag - 4.2 V, 6.0 Amp; Basis metals - 6.8 V, 15.7-15.8 Amp | | | | | | | | | | | | |
| Rostrip 999 | 8-8-91 | Ag | 11 | 10.50 | 1.990 | 1.001 | 0.125 | 0.245 | 32.44 | 40.3345 | 38.1361 | 2.1984 |
| Rostrip 999 | 8-8-91 | Ag | 12 | 10.50 | 1.974 | 0.995 | 0.124 | 0.244 | 32.00 | 39.1034 | 36.9825 | 2.1209 |
| Rostrip 999 | 8-8-91 | C4340 | 5 | 7.84 | 2.010 | 0.980 | 0.063 | 0.247 | 28.74 | 15.0710 | 15.0614 | 0.0096 |
| Rostrip 999 | 8-8-91 | D6AC | 44 | 8.20 | 2.008 | 0.981 | 0.082 | 0.248 | 29.61 | 20.1083 | 20.0964 | 1.0119 |
| Rostrip 999 | 8-8-91 | 316 | 48 | 8.00 | 2.026 | 1.004 | 0.067 | 0.249 | 29.59 | 14.0512 | 14.0025 | 0.0487 |
| Rostrip 999 | 8-8-91 | 410 | 25 | 7.70 | 2.031 | 1.007 | 0.060 | 0.252 | 29.31 | 14.0753 | 14.0608 | 0.0145 |
| Rostrip 999 | 8-8-91 | I-718 | 33 | 8.60 | 2.031 | 1.018 | 0.063 | 0.246 | 29.81 | 16.3843 | 14.7043 | 1.6800 |
| Rostrip 999 | 8-8-91 | HA-188 | 73 | 9.70 | 1.994 | 1.024 | 0.127 | 0.244 | 33.25 | 35.4594 | 33.3254 | 2.1340 |
| Rostrip 999 | 8-8-91 | 17-4PH | 48 | 7.80 | 1.999 | 1.008 | 0.064 | 0.262 | 29.08 | 15.3061 | 15.2802 | 0.0259 |
| Test Conditions: Ambient Temp., pH 12.0, air agitation, Ag - 3.8 V, 6.0 Amp; Basis metals - 6.5 V, 15.8 Amp | | | | | | | | | | | | |
| Rostrip 999 | 8-15-91 | Ag | 15 | 10.50 | 2.001 | 0.991 | 0.126 | 0.245 | 32.39 | 40.0074 | 38.6150 | 1.3924 |
| Rostrip 999 | 8-15-91 | Ag | 16 | 10.50 | 1.993 | 1.000 | 0.126 | 0.240 | 32.54 | 40.3892 | 38.2832 | 2.1060 |
| Rostrip 999 | 8-15-91 | C4340 | 1 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.1135 | 15.1036 | 0.0099 |
| Rostrip 999 | 8-15-91 | D6AC | 54 | 8.20 | 2.010 | 0.990 | 0.084 | 0.244 | 30.02 | 19.3006 | 19.2878 | 0.0128 |
| Rostrip 999 | 8-15-91 | 316 | 40 | 8.00 | 2.029 | 1.010 | 0.068 | 0.248 | 29.86 | 13.6944 | 13.6616 | 0.0328 |
| Rostrip 999 | 8-15-91 | 410 | 23 | 7.70 | 2.028 | 1.008 | 0.061 | 0.253 | 29.35 | 14.3021 | 14.2826 | 0.0195 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions - in inches - | | | hole | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|--------------|-----------|-------------------|-------------------------------------|-----------------------------------|-------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | Length | width | thick | | | | | | | | |
| Rosstrip 999 | 8-15-91 | I-718 | 39 | 8.60 | 2.019 | 1.002 | 0.063 | 0.254 | 29.18 | 16.1705 | 13.9878 | 2.1827 | 1.0 | 3.42E+00 |
| Rosstrip 999 | 8-15-91 | HA-188 | 77 | 9.70 | 1.993 | 1.007 | 0.127 | 0.245 | 32.77 | 36.0166 | 33.7214 | 2.2952 | 1.0 | 2.84E+00 |
| Rosstrip 999 | 8-15-91 | 17-4PH | 39 | 7.80 | 2.007 | 1.004 | 0.063 | 0.249 | 29.09 | 15.2019 | 15.1798 | 0.0221 | 1.0 | 3.83E-02 |

C-101 Process (USAF Electrolytic Cyanide Process)
Test Conditions: Ambient Temp. (91F), pH 13.0, air agitation, Ag - 3.0 V, 3.0 Amp; Basis metals - 5.0 V, 17.5 Amp

| | | | | | | | | | | | | | | |
|-------|---------|--------|----|-------|-------|-------|-------|-------|-------|---------|---------|--------|------|----------|
| C-101 | 7-11-91 | Ag | 3 | 10.50 | 1.989 | 1.000 | 0.125 | 0.243 | 32.41 | 40.0008 | 39.6794 | 0.3214 | 0.25 | 1.49E+00 |
| C-101 | 7-11-91 | Ag | 4 | 10.50 | 1.994 | 0.978 | 0.126 | 0.244 | 31.94 | 38.9552 | 37.7118 | 1.2434 | 0.25 | 5.84E+00 |
| C-101 | 7-11-91 | CA340 | 9 | 7.84 | 2.007 | 0.987 | 0.062 | 0.253 | 28.56 | 15.0767 | 15.0657 | 0.0110 | 3.0 | 6.45E-03 |
| C-101 | 7-11-91 | D6AC | 42 | 8.20 | 2.023 | 0.999 | 0.080 | 0.250 | 30.18 | 19.5462 | 19.5326 | 0.0136 | 3.0 | 7.21E-03 |
| C-101 | 7-11-91 | 316 | 52 | 8.00 | 2.027 | 1.006 | 0.068 | 0.250 | 29.71 | 13.8846 | 13.8643 | 0.0203 | 3.0 | 1.12E-02 |
| C-101 | 7-11-91 | 410 | 29 | 7.70 | 2.026 | 1.006 | 0.061 | 0.253 | 29.27 | 14.0379 | 14.0114 | 0.0265 | 3.0 | 1.54E-02 |
| C-101 | 7-11-91 | I-718 | 31 | 8.60 | 2.013 | 1.000 | 0.063 | 0.245 | 29.08 | 16.1601 | 16.1419 | 0.0182 | 3.0 | 9.55E-03 |
| C-101 | 7-11-91 | HA-188 | 26 | 9.70 | 1.993 | 1.005 | 0.125 | 0.246 | 32.59 | 35.2773 | 35.1304 | 0.1469 | 3.0 | 6.10E-02 |
| C-101 | 7-11-91 | 17-4PH | 43 | 7.80 | 2.011 | 1.009 | 0.063 | 0.250 | 29.27 | 15.1810 | 15.1481 | 0.0329 | 3.0 | 1.89E-02 |

Test Conditions: Ambient Temp., pH 13.0, air agitation, Ag - 4.0 V, 6.0 Amp; Basis metals - 4.6 V, 15.8 Amp

| | | | | | | | | | | | | | | |
|-------|---------|--------|----|-------|-------|-------|-------|-------|-------|---------|---------|--------|------|----------|
| C-101 | 7-26-91 | Ag | 1 | 10.50 | 1.992 | 1.003 | 0.126 | 0.244 | 32.59 | 39.9893 | 38.7150 | 1.2743 | 0.25 | 5.86E+00 |
| C-101 | 7-26-91 | Ag | 2 | 10.50 | 2.000 | 0.994 | 0.126 | 0.243 | 32.47 | 40.0774 | 38.6737 | 1.4037 | 0.25 | 6.48E+00 |
| C-101 | 7-26-91 | CA340 | 91 | 7.84 | 2.004 | 1.024 | 0.062 | 0.251 | 29.51 | 15.2537 | 15.2503 | 0.0034 | 2.0 | 2.89E-03 |
| C-101 | 7-26-91 | D6AC | 19 | 8.20 | 2.017 | 0.993 | 0.084 | 0.249 | 30.17 | 20.1042 | 20.0991 | 0.0051 | 2.0 | 4.06E-03 |
| C-101 | 7-26-91 | 316 | 37 | 8.90 | 2.029 | 1.006 | 0.068 | 0.250 | 29.74 | 14.0119 | 14.0030 | 0.0089 | 2.0 | 7.36E-03 |
| C-101 | 7-26-91 | 410 | 18 | 7.70 | 2.011 | 1.008 | 0.059 | 0.254 | 28.99 | 13.8061 | 13.7922 | 0.0139 | 2.0 | 1.23E-02 |
| C-101 | 7-26-91 | I-718 | 22 | 8.60 | 2.003 | 1.004 | 0.062 | 0.244 | 29.00 | 15.7564 | 15.7445 | 0.0119 | 2.0 | 9.39E-03 |
| C-101 | 7-26-91 | HA-188 | 80 | 9.70 | 2.025 | 1.008 | 0.126 | 0.246 | 33.20 | 36.2075 | 36.1428 | 0.0647 | 2.0 | 3.95E-02 |
| C-101 | 7-26-91 | 17-4PH | 35 | 7.80 | 2.003 | 1.010 | 0.061 | 0.258 | 29.03 | 15.0552 | 15.0407 | 0.0145 | 2.0 | 1.26E-02 |

APPENDIX E

**STRIPPING RATE DATA FOR THE FIELD TESTING OF
EG&G IDAHO, INC.'S GENERIC NICKEL STRIPPER**

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions -----in inches----- | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) | |
|---|--|-------------------|-------------------------------------|---|-------|-----------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|----------|
| | | | | length | width | thickness | | | | | | | | |
| Generic Nickel Stripper Development - all 2L volumes with mechanical agitation | | | | | | | | | | | | | | |
| Temp 130F | EN 20XV, HNO ₃ var., Na m-NBS 10%w, NH ₄ SCN 0.5%w | | | | | | | | | | | | | |
| Generic 1 | 5-21-91 Ni-S** | 17 | 8.90 | 2.038 | 0.075 | 0.241 | 30.91 | 19.2947 | 17.0310 | 2.2637 | 1.0 | 3.24E+00 | 3.11E+00 | |
| Generic 1 | 5-21-91 Ni-S** | 19 | 8.90 | 2.026 | 0.072 | 0.239 | 30.41 | 18.2996 | 16.2464 | 2.0532 | 1.0 | 2.99E+00 | | |
| Generic 1 | 5-22-91 Ni-S | 305 | 8.90 | 2.044 | 0.042 | 0.077 | 0.236 | 31.54 | 21.9088 | 19.7838 | 2.1250 | 1.0 | 2.98E+00 | 2.88E+00 |
| Generic 1 | 5-22-91 Ni-S | 309 | 8.90 | 2.058 | 1.051 | 0.079 | 0.232 | 32.13 | 23.5875 | 21.5776 | 2.0115 | 1.0 | 2.77E+00 | |
| Generic 1 | 5-21-91 Ni-P | 116 | 8.90 | 2.004 | 1.012 | 0.071 | 0.243 | 29.76 | 17.8604 | 17.8499 | 0.0105 | 2.0 | 7.80E-03 | 2.10E-01 |
| Generic 1 | 5-21-91 Ni-P | 131 | 8.90 | 2.021 | 1.012 | 0.072 | 0.239 | 30.08 | 18.7734 | 18.1626 | 0.5008 | 2.0 | 4.12E-01 | |
| Generic 1 | 5-21-91 C4340 | 55 | 7.84 | 2.006 | 1.021 | 0.062 | 0.250 | 29.46 | 15.3213 | 15.3105 | 0.0108 | 24.0 | 7.67E-04 | 7.24E-04 |
| Generic 1 | 5-21-91 C4340 | 56 | 7.84 | 2.007 | 1.021 | 0.062 | 0.244 | 29.51 | 15.1785 | 15.1689 | 0.0096 | 24.0 | 6.81E-04 | |
| Generic 1 | 5-21-91 D6AC | 1 | 8.20 | 1.989 | 0.999 | 0.081 | 0.250 | 29.76 | 19.5983 | 19.5827 | 0.0556 | 24.0 | 1.05E-03 | 1.13E-03 |
| Generic 1 | 5-21-91 D6AC | 2 | 8.20 | 2.016 | 0.995 | 0.083 | 0.249 | 30.15 | 19.9179 | 19.8995 | 0.0184 | 24.0 | 1.22E-03 | |
| Generic 1 | 5-21-91 316SS | 19 | 8.00 | 2.017 | 1.002 | 0.067 | 0.249 | 29.41 | 13.8338 | 13.8333 | 0.0005 | 24.0 | 3.49E-05 | 3.47E-05 |
| Generic 1 | 5-21-91 316SS | 20 | 8.00 | 2.028 | 1.007 | 0.068 | 0.248 | 29.76 | 14.0402 | 14.0397 | 0.0005 | 24.0 | 3.44E-05 | |
| Generic 1 | 5-21-91 410SS | 1 | 7.70 | 2.023 | 1.008 | 0.059 | 0.252 | 29.16 | 14.0624 | 14.0618 | 0.0006 | 24.0 | 4.38E-05 | 1.28E-04 |
| Generic 1 | 5-21-91 410SS | 2 | 7.70 | 2.022 | 1.006 | 0.058 | 0.253 | 29.03 | 13.8191 | 13.8162 | 0.0029 | 24.0 | 2.13E-04 | |
| Generic 1 | 5-21-91 I-718 | 1 | 8.60 | 1.979 | 1.004 | 0.063 | 0.245 | 28.72 | 15.6645 | 15.6641 | 0.0004 | 24.0 | 2.66E-05 | 1.98E-05 |
| Generic 1 | 5-21-91 I-718 | 2 | 8.60 | 2.008 | 1.004 | 0.063 | 0.247 | 29.11 | 16.1215 | 16.1213 | 0.0002 | 24.0 | 1.31E-05 | |
| Generic 1 | 5-21-91 HA188 | 1 | 9.70 | 2.019 | 1.005 | 0.124 | 0.243 | 32.93 | 35.1748 | 35.1743 | 0.0005 | 24.0 | 2.57E-05 | 3.09E-05 |
| Generic 1 | 5-21-91 HA188 | 2 | 9.70 | 1.993 | 1.008 | 0.126 | 0.245 | 32.74 | 35.5969 | 35.5962 | 0.0005 | 24.0 | 3.62E-05 | |
| Generic 1 | 5-21-91 17-4PH | 19 | 7.80 | 2.005 | 1.004 | 0.062 | 0.266 | 28.91 | 14.4908 | 14.4900 | 0.0008 | 24.0 | 5.82E-05 | 6.91E-05 |
| Generic 1 | 5-21-91 17-4PH | 20 | 7.80 | 1.992 | 1.007 | 0.063 | 0.260 | 28.91 | 15.0571 | 15.0560 | 0.0011 | 24.0 | 8.00E-05 | |
| ** Denotes bad batch of sulfonate nickel coupons that were stripped down to the basis metal | | | | | | | | | | | | | | |
| Temp 10.42 | EN 20XV, HNO ₃ var., Na m-NBS 10%w, NH ₄ SCN 0.5%w | | | | | | | | | | | | | |
| Generic 1 | 5-21-91 Ni-S** | 18 | 8.90 | 2.025 | 1.014 | 0.070 | 0.241 | 30.06 | 17.5202 | 15.5203 | 1.9999 | 1.0 | 2.94E+00 | 3.22E+00 |
| Generic 1 | 5-21-91 Ni-S** | 167 | 8.90 | 2.033 | 1.034 | 0.075 | 0.240 | 31.04 | 19.5812 | 17.1267 | 2.4545 | 1.0 | 3.50E+00 | |
| Generic 1 | 5-22-91 Ni-S | 357 | 8.90 | 2.048 | 1.038 | 0.075 | 0.237 | 31.36 | 21.4929 | 19.1999 | 2.2930 | 1.0 | 3.23E+00 | 3.18E+00 |
| Generic 1 | 5-22-91 Ni-S | 360 | 8.90 | 2.049 | 1.047 | 0.082 | 0.236 | 32.05 | 22.8358 | 20.5722 | 2.2636 | 1.0 | 3.12E+00 | |
| Generic 1 | 5-21-91 Ni-P | 20 | 8.90 | 2.022 | 1.015 | 0.072 | 0.239 | 30.18 | 18.1684 | 18.1498 | 0.0186 | 2.0 | 1.36E-02 | 8.86E-03 |
| Generic 1 | 5-21-91 Ni-P | 26 | 8.90 | 2.030 | 1.014 | 0.072 | 0.235 | 30.28 | 18.3622 | 18.3566 | 0.0056 | 2.0 | 4.09E-03 | |
| Generic 1 | 5-21-91 C4340 | 58 | 7.84 | 1.996 | 1.022 | 0.062 | 0.248 | 29.36 | 15.3130 | 15.3122 | 0.0008 | 24.0 | 5.70E-05 | 5.69E-05 |
| Generic 1 | 5-21-91 C4340 | 59 | 7.84 | 1.998 | 1.023 | 0.063 | 0.250 | 29.47 | 15.3344 | 15.3336 | 0.0008 | 24.0 | 5.68E-05 | |
| Generic 1 | 5-21-91 D6AC | 4 | 8.20 | 2.010 | 0.990 | 0.085 | 0.248 | 30.06 | 20.2771 | 20.2759 | 0.0012 | 24.0 | 7.99E-05 | 6.66E-05 |
| Generic 1 | 5-21-91 D6AC | 5 | 8.20 | 2.013 | 0.994 | 0.081 | 0.249 | 29.97 | 19.4804 | 19.4796 | 0.0008 | 24.0 | 5.34E-05 | |
| Generic 1 | 5-21-91 316SS | 21 | 8.00 | 2.015 | 1.005 | 0.066 | 0.248 | 29.41 | 13.4675 | 13.4675 | 0.0000 | 24.0 | 0.00E+00 | 1.39E-05 |
| Generic 1 | 5-21-91 316SS | 22 | 8.00 | 2.006 | 1.006 | 0.068 | 0.248 | 29.43 | 14.0015 | 14.0011 | 0.0004 | 24.0 | 2.79E-05 | |
| Generic 1 | 5-21-91 410SS | 3 | 7.70 | 2.015 | 1.008 | 0.060 | 0.254 | 29.10 | 13.9824 | 13.9822 | 0.0002 | 24.0 | 1.46E-05 | 4.03E-05 |
| Generic 1 | 5-21-91 410SS | 4 | 7.70 | 2.013 | 1.009 | 0.059 | 0.248 | 29.07 | 13.8292 | 13.8283 | 0.0009 | 24.0 | 6.59E-05 | |
| Generic 1 | 5-21-91 I-718 | 3 | 8.60 | 2.011 | 1.000 | 0.063 | 0.246 | 29.05 | 15.9335 | 15.9331 | 0.0004 | 24.0 | 2.63E-05 | 4.58E-05 |
| Generic 1 | 5-21-91 I-718 | 4 | 8.60 | 2.015 | 1.002 | 0.063 | 0.247 | 29.16 | 16.2494 | 16.2484 | 0.0010 | 24.0 | 6.54E-05 | |
| Generic 1 | 5-21-91 HA188 | 3 | 9.70 | 2.010 | 1.005 | 0.126 | 0.244 | 32.91 | 35.7509 | 35.7297 | 0.0012 | 24.0 | 6.17E-05 | 5.89E-05 |
| Generic 1 | 5-21-91 HA188 | 4 | 9.70 | 2.025 | 1.007 | 0.126 | 0.243 | 33.19 | 36.1202 | 36.1191 | 0.0011 | 24.0 | 5.61E-05 | |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) | |
|---|-----------|---|-------------------------------------|---------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|-----------|
| | | | | length | width | thick | | | | | | | | |
| Generic 1 | 5-21-91 | 17-4PH | 21 | 7.80 | 2.013 | 1.007 | 0.258 | 29.21 | 15.2192 | 0.0004 | 24.0 | 2.88E-05 | 3.49E-06 | |
| Generic 1 | 5-21-91 | 17-4PH | 22 | 7.80 | 1.996 | 1.005 | 0.263 | 28.90 | 15.2104 | 15.2107 | -0.0003 | 24.0 | -2.18E-05 | |
| ** Denotes bad batch of sulfamate nickel coupons that were stripped down to the basis metal | | | | | | | | | | | | | | |
| Temp 130F | PH 11.02 | EN 20Xv, HNO ₃ var., Na m-NBS 10Xw, Na4SCN 0.5Xw | | | | | | | | | | | | |
| Generic 1 | 5-21-91 | Na-S** | 30 | 8.90 | 2.038 | 1.018 | 0.069 | 0.242 | 30.30 | 17.7519 | 15.7805 | 1.9714 | 1.0 | 2.88E+00 |
| Generic 1 | 5-21-91 | Na-S** | 43 | 8.90 | 2.024 | 1.023 | 0.073 | 0.238 | 30.47 | 18.5180 | 16.4397 | 2.0783 | 1.0 | 3.02E+00 |
| Generic 1 | 5-22-91 | Na-S | 400 | 8.90 | 2.048 | 1.037 | 0.081 | 0.236 | 31.70 | 20.9852 | 18.7411 | 2.2441 | 1.0 | 3.13E+00 |
| Generic 1 | 5-22-91 | Na-S | 407 | 8.90 | 2.054 | 1.046 | 0.084 | 0.231 | 32.24 | 23.5698 | 21.3521 | 2.2177 | 1.0 | 3.04E+00 |
| Generic 1 | 5-21-91 | Na-P | 32 | 8.90 | 2.010 | 1.008 | 0.069 | 0.241 | 29.63 | 17.0159 | 17.0135 | 0.0024 | 2.0 | 1.79E-03 |
| Generic 1 | 5-21-91 | Na-P | 43 | 8.90 | 2.015 | 1.014 | 0.072 | 0.238 | 30.06 | 17.8769 | 17.8693 | 0.0076 | 2.0 | 5.59E-03 |
| Generic 1 | 5-21-91 | C4340 | 61 | 7.84 | 1.994 | 1.028 | 0.063 | 0.250 | 29.54 | 15.4014 | 15.4015 | -0.0001 | 24.0 | -7.08E-06 |
| Generic 1 | 5-21-91 | C4340 | 62 | 7.84 | 2.010 | 1.016 | 0.062 | 0.251 | 29.33 | 15.1955 | 15.1952 | 0.0003 | 24.0 | 2.14E-05 |
| Generic 1 | 5-21-91 | D6AC | 6 | 8.20 | 2.015 | 1.001 | 0.086 | 0.256 | 30.31 | 10.1241 | 20.1238 | 0.0003 | 24.0 | 1.98E-05 |
| Generic 1 | 5-21-91 | D6AC | 7 | 8.20 | 2.013 | 1.001 | 0.085 | 0.250 | 30.39 | 20.4171 | 20.4170 | 0.0001 | 24.0 | 6.58E-06 |
| Generic 1 | 5-21-91 | 316ss | 23 | 8.00 | 2.026 | 1.003 | 0.068 | 0.244 | 29.65 | 13.7991 | 13.7992 | -0.0001 | 24.0 | -6.92E-06 |
| Generic 1 | 5-21-91 | 316ss | 24 | 8.00 | 2.029 | 1.005 | 0.068 | 0.248 | 29.72 | 14.2848 | 14.2849 | -0.0001 | 24.0 | -6.90E-06 |
| Generic 1 | 5-21-91 | 410ss | 5 | 7.70 | 2.019 | 1.005 | 0.059 | 0.249 | 29.04 | 14.2339 | 14.2338 | 0.0001 | 24.0 | 2.93E-05 |
| Generic 1 | 5-21-91 | 410ss | 6 | 7.70 | 2.015 | 1.009 | 0.059 | 0.255 | 29.07 | 13.9444 | 13.9437 | 0.0007 | 24.0 | 5.13E-05 |
| Generic 1 | 5-21-91 | 5 | 8.60 | 1.989 | 0.998 | 0.063 | 0.246 | 28.70 | 15.7825 | 15.7823 | 0.0002 | 24.0 | 1.33E-05 | |
| Generic 1 | 5-21-91 | 1-718 | 6 | 8.60 | 2.009 | 1.003 | 0.063 | 0.244 | 29.12 | 16.0231 | 16.0229 | 0.0002 | 24.0 | 1.31E-05 |
| Generic 1 | 5-21-91 | HA188 | 6 | 9.70 | 2.006 | 1.005 | 0.127 | 0.247 | 32.90 | 35.8734 | 35.8726 | 0.0008 | 24.0 | 4.11E-05 |
| Generic 1 | 5-21-91 | HA188 | 5 | 9.70 | 2.003 | 1.001 | 0.126 | 0.247 | 32.68 | 35.5869 | 35.5867 | 0.0002 | 24.0 | 1.03E-05 |
| Generic 1 | 5-21-91 | 17-4PH | 23 | 7.80 | 1.995 | 1.004 | 0.063 | 0.260 | 28.87 | 14.7565 | 14.7564 | 0.0001 | 24.0 | 7.29E-06 |
| Generic 1 | 5-21-91 | 17-4PH | 24 | 7.80 | 1.999 | 1.009 | 0.061 | 0.260 | 28.94 | 14.6363 | 14.6365 | -0.0002 | 24.0 | -3.63E-06 |
| ** Denotes bad batch of sulfamate nickel coupons that were stripped down to the basis metal | | | | | | | | | | | | | | |
| Temp 130F | PH 10.15 | EN 20Xv, HNO ₃ (conc.) 6.5Xw, Na m-NBS 10Xw, Na4SCN 0.05Xw*** or 0.5Xw | | | | | | | | | | | | |
| Generic rf | 5-28-91 | Na-S** | 525 | 8.90 | 2.048 | 1.045 | 0.083 | 0.232 | 32.06 | 22.5831 | 20.0927 | 2.4904 | 1.0 | 3.44E+00 |
| Generic rf | 5-28-91 | Na-S** | 527 | 8.90 | 2.068 | 1.053 | 0.087 | 0.232 | 32.81 | 24.9815 | 22.2133 | 2.4682 | 1.0 | 3.33E+00 |
| Generic rf | 5-28-91 | Na-P** | 85 | 8.90 | 2.022 | 1.013 | 0.072 | 0.237 | 30.13 | 18.1288 | 18.1177 | 0.0111 | 1.0 | 1.63E-02 |
| Generic rf | 5-28-91 | Na-P** | 86 | 8.90 | 2.019 | 1.012 | 0.071 | 0.237 | 30.00 | 17.9200 | 17.9133 | 0.0067 | 1.0 | 9.88E-03 |
| Generic rf | 5-28-91 | Na-S | 435 | 8.90 | 2.053 | 1.037 | 0.077 | 0.232 | 31.55 | 21.3931 | 19.1131 | 2.2800 | 1.0 | 3.20E+00 |
| Generic rf | 5-28-91 | Na-S | 470 | 8.90 | 2.030 | 1.063 | 0.096 | 0.228 | 33.09 | 27.3565 | 25.0411 | 2.3154 | 1.0 | 3.10E+00 |
| Generic rf | 5-28-91 | Na-P | 111 | 8.90 | 2.031 | 1.014 | 0.072 | 0.241 | 30.27 | 18.3330 | 18.3233 | 0.0097 | 1.0 | 1.42E-02 |
| Generic rf | 5-28-91 | Na-P | 113 | 8.90 | 2.022 | 1.016 | 0.071 | 0.237 | 30.15 | 18.0490 | 18.0432 | 0.0058 | 1.0 | 8.51E-03 |
| Generic rf | 5-28-91 | 316 | 41 | 8.00 | 2.026 | 1.028 | 0.069 | 0.251 | 30.35 | 14.1624 | 14.1620 | 0.0006 | 24.0 | 2.70E-05 |
| Generic rf | 5-28-91 | 410 | 91 | 7.70 | 2.039 | 1.006 | 0.059 | 0.254 | 29.18 | 13.9782 | 13.9781 | 0.0001 | 24.0 | 7.30E-06 |
| Generic rf | 5-28-91 | 17-4PH | 70 | 7.80 | 2.009 | 1.003 | 0.061 | 0.257 | 28.93 | 14.7096 | 14.7096 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | D6AC | 49 | 8.20 | 2.003 | 0.997 | 0.079 | 0.250 | 29.79 | 19.2793 | 19.2793 | 0.0005 | 24.0 | 3.36E-05 |
| Generic rf | 5-28-91 | HA188 | 8 | 9.70 | 2.015 | 1.002 | 0.126 | 0.247 | 32.88 | 35.9947 | 35.9947 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | 1718 | 7 | 8.60 | 2.020 | 1.006 | 0.063 | 0.246 | 29.34 | 16.2955 | 16.2955 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | C4340 | 60 | 7.84 | 1.991 | 1.023 | 0.061 | 0.253 | 29.23 | 15.0490 | 15.0487 | 0.0003 | 24.0 | 2.15E-05 |

Retry with Formulation minus all ammonia sources

| Temp 130F | PH 10.15 | EN 20Xv, HNO ₃ (conc.) 6.5Xw, Na m-NBS 10Xw, Na4SCN 0.05Xw*** or 0.5Xw | Formulation minus all ammonia sources | | | | | | | | | | | |
|------------|----------|---|---------------------------------------|--------|-------|-------|-------|-------|-------|---------|---------|--------|------|----------|
| | | | Na-S** | Na-P** | Na-S | Na-P | Na-S | Na-P | Na-S | Na-P | Na-S | Na-P | Na-S | Na-P |
| Generic rf | 5-28-91 | Na-S** | 525 | 8.90 | 2.048 | 1.053 | 0.083 | 0.232 | 32.81 | 24.9815 | 22.2133 | 2.4682 | 1.0 | 3.33E+00 |
| Generic rf | 5-28-91 | Na-S** | 527 | 8.90 | 2.068 | 1.055 | 0.087 | 0.232 | 32.81 | 24.9815 | 22.2133 | 2.4682 | 1.0 | 3.33E+00 |
| Generic rf | 5-28-91 | Na-P** | 85 | 8.90 | 2.022 | 1.013 | 0.072 | 0.237 | 30.13 | 18.1288 | 18.1177 | 0.0111 | 1.0 | 1.63E-02 |
| Generic rf | 5-28-91 | Na-P** | 86 | 8.90 | 2.019 | 1.012 | 0.071 | 0.237 | 30.00 | 17.9200 | 17.9133 | 0.0067 | 1.0 | 9.88E-03 |
| Generic rf | 5-28-91 | Na-S | 435 | 8.90 | 2.053 | 1.037 | 0.077 | 0.232 | 31.55 | 21.3931 | 19.1131 | 2.2800 | 1.0 | 3.20E+00 |
| Generic rf | 5-28-91 | Na-S | 470 | 8.90 | 2.030 | 1.063 | 0.096 | 0.228 | 33.09 | 27.3565 | 25.0411 | 2.3154 | 1.0 | 3.10E+00 |
| Generic rf | 5-28-91 | Na-P | 111 | 8.90 | 2.031 | 1.014 | 0.072 | 0.241 | 30.27 | 18.3330 | 18.3233 | 0.0097 | 1.0 | 1.42E-02 |
| Generic rf | 5-28-91 | Na-P | 113 | 8.90 | 2.022 | 1.016 | 0.071 | 0.237 | 30.15 | 18.0490 | 18.0432 | 0.0058 | 1.0 | 8.51E-03 |
| Generic rf | 5-28-91 | 316 | 41 | 8.00 | 2.026 | 1.028 | 0.069 | 0.251 | 30.35 | 14.1624 | 14.1620 | 0.0006 | 24.0 | 2.70E-05 |
| Generic rf | 5-28-91 | 410 | 91 | 7.70 | 2.039 | 1.006 | 0.059 | 0.254 | 29.18 | 13.9782 | 13.9781 | 0.0001 | 24.0 | 7.30E-06 |
| Generic rf | 5-28-91 | 17-4PH | 70 | 7.80 | 2.009 | 1.003 | 0.061 | 0.257 | 28.93 | 14.7096 | 14.7096 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | D6AC | 49 | 8.20 | 2.003 | 0.997 | 0.079 | 0.250 | 29.79 | 19.2793 | 19.2793 | 0.0005 | 24.0 | 3.36E-05 |
| Generic rf | 5-28-91 | HA188 | 8 | 9.70 | 2.015 | 1.002 | 0.126 | 0.247 | 32.88 | 35.9947 | 35.9947 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | 1718 | 7 | 8.60 | 2.020 | 1.006 | 0.063 | 0.246 | 29.34 | 16.2955 | 16.2955 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 5-28-91 | C4340 | 60 | 7.84 | 1.991 | 1.023 | 0.061 | 0.253 | 29.23 | 15.0490 | 15.0487 | 0.0003 | 24.0 | 2.15E-05 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions - length in inches | Unmasked Dimensions - width thick | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|--|-----------|-------------------|-------------------------------------|--|-----------------------------------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| Generic Reformulation pH Tests using measured HNO₃ concentrations 2L volumes with mechanical agitation | | | | | | | | | | | | |
| 5% Vol HNO₃ + EN 20%v, Na m-NBS 10%w, NaSCN 0.1%w | | | | | | | | | | | | |
| Generic rf 6-3-91 | Ni-S | 522 | 8.90 | 2.061 | 1.061 | 0.083 | 0.229 | 32.70 | 25.0952 | 22.3855 | 2.7097 | 1.0 |
| Generic rf 6-3-91 | Ni-S | 595 | 8.90 | 2.052 | 1.048 | 0.081 | 0.233 | 32.07 | 22.5595 | 20.4006 | 2.5589 | 1.0 |
| Generic rf 6-3-91 | C4340 | 66 | 7.84 | 1.999 | 1.025 | 0.062 | 0.253 | 29.46 | 15.1581 | 15.1585 | -0.0004 | 24.0 |
| Generic rf 6-3-91 | D6AC | 8 | 8.20 | 2.015 | 0.999 | 0.084 | 0.250 | 30.30 | 20.0083 | 20.6075 | 0.0008 | 24.0 |
| Generic rf 6-3-91 | C410ss | 26 | 8.00 | 2.025 | 1.004 | 0.067 | 0.250 | 29.57 | 14.0741 | 14.0737 | 0.0004 | 24.0 |
| Generic rf 6-3-91 | 316ss | 7 | 7.70 | 2.027 | 1.002 | 0.058 | 0.255 | 28.98 | 13.8055 | 13.8051 | 0.0004 | 24.0 |
| Generic rf 6-3-91 | 410ss | 25 | 7.80 | 1.995 | 1.004 | 0.063 | 0.260 | 28.87 | 14.9076 | 14.9072 | 0.0004 | 24.0 |
| Generic rf 6-3-91 | 17-4PH | 12 | 9.70 | 2.020 | 1.006 | 0.126 | 0.245 | 33.08 | 36.1585 | 36.1582 | 0.0003 | 24.0 |
| Generic rf 6-3-91 | HA188 | 11 | 8.60 | 1.985 | 1.004 | 0.062 | 0.246 | 28.74 | 15.5853 | 15.5852 | 0.0001 | 24.0 |
| Generic rf 6-3-91 | I-718 | 13 | 8.60 | 1.985 | 1.004 | 0.062 | 0.246 | 28.74 | 15.5853 | 15.5852 | 0.0001 | 24.0 |
| 9% Vol HNO₃ + EN 20%v, Na m-NBS 10%w, NaSCN 0.1%w | | | | | | | | | | | | |
| Generic rf 6-3-91 | Ni-S | 580 | 8.90 | 2.047 | 1.043 | 0.078 | 0.235 | 31.67 | 22.0280 | 19.2849 | 2.7431 | 1.0 |
| Generic rf 6-3-91 | Ni-S | 582 | 8.90 | 2.046 | 1.050 | 0.082 | 0.231 | 32.11 | 23.3112 | 20.675 | 2.6357 | 1.0 |
| Generic rf 6-3-91 | C4340 | 67 | 7.84 | 2.003 | 1.023 | 0.062 | 0.252 | 29.47 | 15.0418 | 15.0412 | 0.0006 | 24.0 |
| Generic rf 6-3-91 | D6AC | 9 | 8.20 | 2.007 | 0.982 | 0.083 | 0.249 | 29.68 | 20.0282 | 20.0278 | 0.0004 | 24.0 |
| Generic rf 6-3-91 | 316ss | 27 | 8.00 | 2.027 | 1.003 | 0.069 | 0.250 | 29.69 | 14.2162 | 14.2159 | 0.0003 | 24.0 |
| Generic rf 6-3-91 | 410ss | 8 | 7.70 | 2.021 | 1.006 | 0.059 | 0.249 | 29.10 | 13.9489 | 13.9486 | 0.0003 | 24.0 |
| Generic rf 6-3-91 | 17-4PH | 26 | 7.80 | 2.012 | 1.004 | 0.063 | 0.258 | 29.11 | 15.1651 | 15.1649 | 0.0002 | 24.0 |
| Generic rf 6-3-91 | HA188 | 13 | 9.70 | 2.004 | 1.006 | 0.126 | 0.247 | 32.83 | 35.7734 | 35.7731 | 0.0003 | 24.0 |
| Generic rf 6-3-91 | I-718 | 13 | 8.60 | 2.011 | 1.004 | 0.063 | 0.245 | 29.16 | 15.9755 | 15.9754 | 0.0001 | 24.0 |
| Broad pH Tests using 220 mL volumes and magnetic stirring | | | | | | | | | | | | |
| 3X Nitric Acid + EN 20%v, Na m-NBS 10%w, NaSCN 0.1%w | | | | | | | | | | | | |
| Generic rf 6-6-91 | Ni-S | 512 | 8.9 | 2.045 | 1.036 | 0.074 | 0.238 | 31.20 | 20.8538 | 19.3537 | 1.5001 | 1.0 |
| Generic rf 6-6-91 | Ni-S | 522 | 8.9 | 2.056 | 1.049 | 0.075 | 0.237 | 31.81 | 22.3851 | 20.7963 | 1.5888 | 1.0 |
| Generic rf 6-6-91 | C4340 | 63 | 7.84 | 1.998 | 1.025 | 0.062 | 0.251 | 29.45 | 15.2271 | 15.2269 | 0.0002 | 24.0 |
| Generic rf 6-6-91 | C4340 | 69 | 7.84 | 2.008 | 1.028 | 0.062 | 0.253 | 29.66 | 15.4217 | 15.4215 | 0.0002 | 24.0 |
| 7X Nitric Acid + EN 20%v, Na m-NBS 10%w, NaSCN 0.1%w | | | | | | | | | | | | |
| Generic rf 6-6-91 | Ni-S | 548 | 8.9 | 2.034 | 1.035 | 0.074 | 0.236 | 31.02 | 20.8695 | 18.9675 | 1.9020 | 1.0 |
| Generic rf 6-6-91 | Ni-S | 559 | 8.9 | 2.066 | 1.028 | 0.075 | 0.237 | 31.06 | 21.5836 | 19.7168 | 1.8668 | 1.0 |
| Generic rf 6-6-91 | C4340 | 70 | 7.84 | 1.997 | 1.025 | 0.062 | 0.254 | 29.42 | 15.2415 | 15.2415 | 0.0000 | 24.0 |
| Generic rf 6-6-91 | C4340 | 71 | 7.84 | 2.008 | 1.030 | 0.062 | 0.253 | 29.72 | 15.4569 | 15.4561 | 0.0008 | 24.0 |
| 11X Nitric Acid + EN 20%v, Na m-NBS 10%w, NaSCN 0.1%w | | | | | | | | | | | | |
| Generic rf 6-6-91 | Ni-S | 591 | 8.9 | 2.039 | 1.042 | 0.076 | 0.236 | 31.40 | 21.6371 | 19.6953 | 1.9418 | 1.0 |
| Generic rf 6-6-91 | Ni-S | 597 | 8.9 | 2.038 | 1.041 | 0.075 | 0.235 | 31.31 | 21.4305 | 19.5093 | 1.9212 | 1.0 |
| Generic rf 6-6-91 | C4340 | 46 | 7.84 | 2.001 | 1.020 | 0.061 | 0.247 | 29.32 | 15.1619 | 15.1610 | 0.0009 | 24.0 |
| Generic rf 6-6-91 | C4340 | 47 | 7.84 | 2.004 | 1.022 | 0.062 | 0.249 | 29.47 | 15.2918 | 15.2905 | 0.0013 | 24.0 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | hole | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|--------------------|-------------------------------------|---------------------|-------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | length | width | thick | | | | | | | | |
| Generic Stripper Field Test Results: EN 20Kv, Na m-NBS 10%W, HNO3 7%V, NaSCN 0.1%W | | | | | | | | | | | | | | |
| Temp 110F | | | | | | | | | | | | | | |
| Generic rf | 6-11-91 | Ni-S | 304 | 8.90 | 2.052 | 1.043 | 0.079 | 0.235 | 31.80 | 22.8033 | 20.9525 | 1.8508 | 1.0 | 2.57E+00 |
| Generic rf | 6-11-91 | Ni-S | 312 | 8.90 | 2.039 | 1.042 | 0.076 | 0.237 | 31.40 | 21.5277 | 19.8088 | 1.7189 | 1.0 | 2.22E+00 |
| Generic rf | 6-11-91 | Ni-P ^{WW} | 2 | 8.90 | 2.023 | 1.013 | 0.073 | 0.238 | 30.20 | 18.3075 | 18.3052 | 0.0023 | 1.0 | 3.37E-03 |
| Generic rf | 6-11-91 | Ni-P ^{WW} | 3 | 8.90 | 2.015 | 1.014 | 0.072 | 0.238 | 30.06 | 18.1992 | 18.1966 | 0.0026 | 1.0 | 3.83E-03 |
| Generic rf | 6-11-91 | C4340 | 48 | 7.84 | 2.006 | 1.022 | 0.061 | 0.250 | 29.43 | 15.3097 | 15.3087 | 0.0010 | 24.0 | 2.78E-04 |
| Generic rf | 6-11-91 | C4340 | 82 | 7.84 | 1.996 | 1.026 | 0.061 | 0.248 | 29.41 | 15.3209 | 15.3204 | -0.0005 | 24.0 | 3.56E-05 |
| Generic rf | 6-11-91 | D6AC | 12 | 8.20 | 2.006 | 1.002 | 0.078 | 0.253 | 29.89 | 18.9862 | 18.9862 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-11-91 | D6AC | 13 | 8.20 | 2.025 | 1.005 | 0.080 | 0.250 | 30.31 | 19.1078 | 19.1074 | 0.0004 | 24.0 | 2.64E-05 |
| Generic rf | 6-11-91 | 316ss | 30 | 8.00 | 2.009 | 1.002 | 0.068 | 0.249 | 29.36 | 14.0043 | 14.0043 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-11-91 | 316ss | 31 | 8.00 | 2.023 | 1.009 | 0.067 | 0.253 | 29.66 | 13.9160 | 13.9160 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-11-91 | 410ss | 11 | 7.70 | 2.026 | 1.005 | 0.059 | 0.248 | 29.15 | 13.9946 | 13.9945 | 0.0001 | 24.0 | 7.31E-06 |
| Generic rf | 6-11-91 | 410ss | 12 | 7.70 | 2.006 | 1.006 | 0.058 | 0.254 | 28.81 | 13.8531 | 13.8530 | 0.0001 | 24.0 | 7.40E-06 |
| Generic rf | 6-11-91 | 410ss | 12 | 8.60 | 1.982 | 1.001 | 0.062 | 0.245 | 28.63 | 15.6533 | 15.6532 | 0.0001 | 24.0 | 6.66E-06 |
| Generic rf | 6-11-91 | 1-718 | 16 | 8.60 | 2.019 | 1.002 | 0.063 | 0.244 | 29.23 | 16.0717 | 16.0718 | -0.0001 | 24.0 | 6.53E-06 |
| Generic rf | 6-11-91 | HA188 | 7 | 9.70 | 2.011 | 1.008 | 0.127 | 0.244 | 33.07 | 36.3191 | 36.3191 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-11-91 | HA188 | 16 | 9.70 | 2.004 | 0.999 | 0.126 | 0.267 | 32.64 | 35.5155 | 35.5153 | 0.0002 | 24.0 | 1.04E-05 |
| Generic rf | 6-11-91 | 17-4PH | 29 | 7.80 | 2.008 | 1.001 | 0.063 | 0.261 | 28.96 | 14.9441 | 14.9441 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-11-91 | 17-4PH | 30 | 7.80 | 1.993 | 1.004 | 0.063 | 0.259 | 28.85 | 14.9473 | 14.9473 | 0.0000 | 24.0 | 0.00E+00 |
| Temp 130F Re-Formulation: EN 20Kv, Na m-NBS 10%W, HNO3 7%V, NaSCN 0.1%W | | | | | | | | | | | | | | |
| Generic rf | 6-12-91 | Ni-S | 326 | 8.90 | 2.036 | 1.045 | 0.077 | 0.236 | 31.50 | 22.1586 | 19.8885 | 2.2736 | 1.0 | 3.19E+00 |
| Generic rf | 6-12-91 | Ni-S | 329 | 8.90 | 2.050 | 1.036 | 0.077 | 0.236 | 31.46 | 21.3761 | 19.0092 | 2.3669 | 1.0 | 3.33E+00 |
| Generic rf | 6-12-91 | Ni-P ^{WW} | 4 | 8.90 | 2.022 | 1.009 | 0.071 | 0.244 | 29.93 | 18.0119 | 18.0027 | 0.0092 | 1.0 | 1.36E-02 |
| Generic rf | 6-12-91 | Ni-P ^{WW} | 7 | 8.90 | 2.020 | 1.013 | 0.071 | 0.239 | 30.03 | 17.9862 | 17.9771 | 0.0091 | 1.0 | 1.34E-02 |
| Generic rf | 6-12-91 | C4340 | 83 | 7.84 | 2.002 | 1.025 | 0.062 | 0.252 | 29.51 | 15.2966 | 15.2965 | 0.0001 | 24.0 | 2.78E-05 |
| Generic rf | 6-12-91 | C4340 | 84 | 7.84 | 1.995 | 1.025 | 0.062 | 0.250 | 29.42 | 15.2344 | 15.2344 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-12-91 | D6AC | 14 | 8.20 | 2.009 | 0.994 | 0.082 | 0.250 | 29.97 | 20.1308 | 20.1308 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-12-91 | D6AC | 15 | 8.20 | 2.020 | 0.995 | 0.078 | 0.250 | 29.91 | 18.8778 | 18.8779 | 0.0001 | 24.0 | 6.69E-06 |
| Generic rf | 6-12-91 | 316ss | 32 | 8.00 | 2.026 | 1.008 | 0.068 | 0.249 | 29.76 | 14.049 | 14.049 | -0.0006 | 24.0 | -4.13E-05 |
| Generic rf | 6-12-91 | 316ss | 33 | 8.00 | 2.022 | 1.000 | 0.069 | 0.252 | 29.53 | 14.0246 | 14.0246 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-12-91 | 410ss | 13 | 7.70 | 2.010 | 1.009 | 0.058 | 0.253 | 28.95 | 13.7569 | 13.7569 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-12-91 | 410ss | 14 | 7.70 | 2.011 | 1.006 | 0.058 | 0.249 | 28.90 | 13.8679 | 13.8679 | 0.0000 | 24.0 | 0.00E+00 |
| Generic rf | 6-12-91 | 1-718 | 17 | 8.60 | 2.014 | 0.998 | 0.063 | 0.252 | 29.01 | 16.0773 | 16.0773 | -0.0003 | 24.0 | -1.97E-05 |
| Generic rf | 6-12-91 | 1-718 | 18 | 8.60 | 2.009 | 1.004 | 0.064 | 0.246 | 29.19 | 16.0481 | 16.0481 | -0.0006 | 24.0 | -3.92E-05 |
| Generic rf | 6-12-91 | HA188 | 17 | 9.70 | 2.015 | 1.010 | 0.126 | 0.249 | 33.10 | 35.5272 | 35.5274 | -0.0002 | 24.0 | -1.02E-05 |
| Generic rf | 6-12-91 | HA188 | 18 | 9.70 | 2.002 | 1.011 | 0.128 | 0.246 | 33.07 | 36.2941 | 36.2945 | -0.0004 | 24.0 | -2.05E-05 |
| Generic rf | 6-12-91 | 17-4PH | 31 | 7.80 | 2.001 | 1.003 | 0.063 | 0.262 | 28.91 | 14.9944 | 14.9948 | -0.0004 | 24.0 | -2.91E-05 |
| Generic rf | 6-12-91 | 17-4PH | 32 | 7.80 | 2.009 | 1.006 | 0.061 | 0.258 | 29.01 | 14.6324 | 14.6328 | -0.0004 | 24.0 | -2.90E-05 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|---------------------|-------------------------------------|---------------------|-------|-----------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | length | width | thickness | | | | | | |
| Temp 150F Re-Formulation: EN 20XV, Na m-NBS 10XW, HNO₃ 7XV, NaSCN 0.1%w Mechanical agitation pH 10.44 | | | | | | | | | | | | |
| Generic rf | 6-13-91 | Ni-S | .381 | 8.90 | 2.077 | 1.076 | 0.086 | 0.230 | 33.53 | 27.2011 | 23.2654 | 3.9357 |
| Generic rf | 6-13-91 | Ni-S | .411 | 8.90 | 2.076 | 1.064 | 0.090 | 0.236 | 33.40 | 25.2713 | 21.7586 | 3.5127 |
| Generic rf | 6-13-91 | Ni-P ^{III} | .91 | 8.90 | 2.025 | 1.015 | 0.070 | 0.238 | 30.10 | 17.9599 | 17.9534 | 0.0065 |
| Generic rf | 6-13-91 | Ni-P ^{III} | .95 | 8.90 | 2.014 | 1.011 | 0.073 | 0.238 | 30.02 | 17.9348 | 17.9257 | 0.0091 |
| Generic rf | 6-13-91 | C4340 | .88 | 7.84 | 2.004 | 1.023 | 0.061 | 0.250 | 29.43 | 15.2355 | 15.2350 | 0.0005 |
| Generic rf | 6-13-91 | C4340 | .87 | 7.84 | 2.005 | 1.037 | 0.062 | 0.250 | 29.88 | 15.5174 | 15.5177 | -0.0003 |
| Generic rf | 6-13-91 | 17-4PH | .27 | 7.80 | 2.009 | 1.008 | 0.061 | 0.267 | 29.01 | 14.4537 | 14.4539 | -0.0002 |
| Generic rf | 6-13-91 | 17-4PH | .28 | 7.80 | 2.012 | 1.004 | 0.063 | 0.255 | 29.13 | 15.1551 | 15.1551 | -0.0007 |
| Generic rf | 6-13-91 | 316ss | .28 | 8.00 | 2.022 | 1.003 | 0.069 | 0.252 | 29.61 | 14.1846 | 14.1851 | -0.0005 |
| Generic rf | 6-13-91 | 316ss | .29 | 8.00 | 2.009 | 1.004 | 0.068 | 0.247 | 29.42 | 13.9173 | 13.9180 | -0.0007 |
| Generic rf | 6-13-91 | 410ss | .9 | 7.70 | 2.020 | 1.003 | 0.059 | 0.250 | 29.00 | 14.0911 | 14.0913 | -0.0002 |
| Generic rf | 6-13-91 | 410ss | .10 | 7.70 | 2.021 | 1.005 | 0.059 | 0.253 | 29.05 | 13.9648 | 13.9651 | -0.0003 |
| Generic rf | 6-13-91 | 64AC | .10 | 8.20 | 2.011 | 0.999 | 0.080 | 0.249 | 30.02 | 19.1848 | 19.1856 | -0.0008 |
| Generic rf | 6-13-91 | 64AC | .11 | 8.20 | 2.021 | 1.005 | 0.080 | 0.252 | 30.30 | 19.3915 | 19.3918 | -0.0003 |
| Generic rf | 6-13-91 | HA188 | .14 | 9.70 | 2.012 | 1.004 | 0.125 | 0.245 | 32.85 | 35.5264 | 35.5274 | -0.0010 |
| Generic rf | 6-13-91 | HA188 | .15 | 9.70 | 2.017 | 1.004 | 0.126 | 0.249 | 32.96 | 36.0449 | 36.0456 | -0.0007 |
| Generic rf | 6-13-91 | I-718 | .14 | 8.60 | 2.024 | 1.000 | 0.063 | 0.244 | 29.24 | 16.1979 | 16.1985 | -0.0006 |
| Generic rf | 6-13-91 | I-718 | .15 | 8.60 | 2.013 | 1.001 | 0.063 | 0.251 | 29.08 | 16.0281 | 16.0286 | -0.0005 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Initial Area (cm ²) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|--|-----------|-------------------|-------------------------------------|---------------------|-------|-------|---------------------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | length | width | thick | | | | | | |
| Longevity Tests Re-Formulation: EN 204V, Na-NBS 103W, HNO3 7%v, NaClN 0.1%w Fresh solution pH 10.40 | | | | | | | | | | | | |
| Generic rf | 6-13-91 | NI-S | 502 | 8.90 | 2.016 | 1.063 | 0.092 | 0.229 | 32.63 | 26.1832 | 2.8128 | 1.0 |
| Generic rf | 6-13-91 | NI-S | 307 | 8.90 | 2.038 | 1.033 | 0.077 | 0.236 | 31.20 | 20.3431 | 17.7603 | 2.5828 |
| Generic rf | 6-13-91 | NI-P*** | 102 | 8.90 | 2.012 | 1.013 | 0.071 | 0.239 | 29.92 | 17.8725 | 17.8673 | 0.0052 |
| Generic rf | 6-13-91 | NI-P*** | 103 | 8.90 | 2.022 | 1.016 | 0.072 | 0.236 | 30.22 | 18.3413 | 18.3322 | 0.0091 |
| Generic rf | 6-13-91 | C4340 | 89 | 7.84 | 1.987 | 1.025 | 0.062 | 0.249 | 29.31 | 15.3001 | 15.3003 | -0.0002 |
| Generic rf | 6-13-91 | C4340 | 90 | 7.84 | 1.999 | 1.021 | 0.061 | 0.248 | 29.32 | 15.1455 | 15.1459 | -0.0004 |
| Generic rf | 6-13-91 | DoAC | 16 | 7.80 | 1.998 | 0.994 | 0.086 | 0.249 | 30.05 | 20.2880 | 20.2885 | -0.0005 |
| Generic rf | 6-13-91 | DoAC | 17 | 7.80 | 2.014 | 0.985 | 0.083 | 0.250 | 29.85 | 19.6452 | 19.6458 | -0.0006 |
| Generic rf | 6-13-91 | 316SS | 34 | 8.00 | 2.015 | 0.998 | 0.068 | 0.251 | 29.49 | 13.8103 | 13.8104 | -0.0001 |
| Generic rf | 6-13-91 | 316SS | 35 | 8.00 | 2.016 | 1.007 | 0.068 | 0.251 | 29.58 | 13.9876 | 13.9876 | -0.0002 |
| Generic rf | 6-13-91 | 410SS | 15 | 7.70 | 2.010 | 1.006 | 0.059 | 0.254 | 28.92 | 13.7830 | 13.7830 | 0.0000 |
| Generic rf | 6-13-91 | 410SS | 16 | 7.70 | 2.022 | 1.006 | 0.059 | 0.253 | 29.09 | 14.2322 | 14.2327 | -0.0005 |
| Generic rf | 6-13-91 | 1-718 | 19 | 8.20 | 2.023 | 1.000 | 0.063 | 0.246 | 29.22 | 16.0932 | 16.0933 | -0.0001 |
| Generic rf | 6-13-91 | 1-718 | 20 | 8.20 | 2.010 | 1.003 | 0.063 | 0.243 | 29.13 | 15.9861 | 15.9864 | -0.0003 |
| Generic rf | 6-13-91 | HA188 | 19 | 9.70 | 2.020 | 1.009 | 0.126 | 0.245 | 33.16 | 35.9643 | 35.9649 | -0.0006 |
| Generic rf | 6-13-91 | HA188 | 20 | 9.70 | 2.020 | 1.004 | 0.126 | 0.248 | 33.01 | 35.8240 | 35.8249 | -0.0009 |
| Generic rf | 6-13-91 | 17-4PH | 33 | 8.60 | 1.994 | 1.004 | 0.063 | 0.248 | 28.92 | 15.2314 | 15.2314 | -0.0002 |
| Generic rf | 6-13-91 | 17-4PH | 34 | 8.60 | 2.002 | 1.006 | 0.062 | 0.261 | 28.95 | 14.8104 | 14.8106 | -0.0002 |
| 1 Week Old pH 10.41 | | | | | | | | | | | | |
| Generic rf | 6-20-91 | NI-S | 319 | 8.90 | 2.059 | 1.058 | 0.082 | 0.233 | 33.17 | 26.2217 | 23.5641 | 2.6576 |
| Generic rf | 6-20-91 | NI-S | 323 | 8.90 | 2.077 | 1.065 | 0.085 | 0.230 | 30.04 | 18.0609 | 18.062 | 0.0047 |
| Generic rf | 6-20-91 | NI-P*** | 9 | 8.90 | 2.020 | 1.013 | 0.071 | 0.237 | 30.04 | 18.0204 | 18.0204 | 1.0 |
| Generic rf | 6-20-91 | NI-P*** | 12 | 8.90 | 2.020 | 1.012 | 0.072 | 0.237 | 30.08 | 18.1789 | 18.1784 | 1.0 |
| Generic rf | 6-20-91 | C4340 | 49 | 7.84 | 2.007 | 1.021 | 0.062 | 0.249 | 29.48 | 15.2637 | 15.2634 | 0.0003 |
| Generic rf | 6-20-91 | C4340 | 91 | 7.84 | 2.004 | 1.024 | 0.062 | 0.251 | 29.51 | 15.2553 | 15.2540 | 0.0013 |
| Generic rf | 6-20-91 | DoAC | 18 | 8.20 | 2.008 | 0.998 | 0.079 | 0.253 | 29.87 | 19.2197 | 19.2191 | 0.0006 |
| Generic rf | 6-20-91 | DoAC | 19 | 8.20 | 2.017 | 0.993 | 0.084 | 0.249 | 30.17 | 20.1050 | 20.1041 | 0.0009 |
| Generic rf | 6-20-91 | 316SS | 36 | 8.00 | 2.011 | 1.005 | 0.068 | 0.251 | 29.46 | 14.0123 | 14.0116 | 0.0007 |
| Generic rf | 6-20-91 | 316SS | 37 | 8.00 | 2.029 | 1.006 | 0.068 | 0.250 | 29.74 | 14.0122 | 14.0116 | 0.0006 |
| Generic rf | 6-20-91 | 410SS | 17 | 7.70 | 2.008 | 1.005 | 0.059 | 0.256 | 28.86 | 14.1260 | 14.1251 | 0.0009 |
| Generic rf | 6-20-91 | 410SS | 18 | 7.70 | 2.011 | 1.008 | 0.059 | 0.254 | 28.99 | 13.8080 | 13.8062 | 0.0018 |
| Generic rf | 6-20-91 | 1-718 | 21 | 8.60 | 2.023 | 1.005 | 0.063 | 0.245 | 29.36 | 15.9793 | 15.9788 | 0.0005 |
| Generic rf | 6-20-91 | 1-718 | 22 | 8.60 | 2.003 | 1.004 | 0.062 | 0.244 | 29.00 | 15.7561 | 15.7561 | 0.0005 |
| Generic rf | 6-20-91 | HA188 | 79 | 9.70 | 2.003 | 1.012 | 0.127 | 0.245 | 33.05 | 36.2779 | 36.2774 | 0.0005 |
| Generic rf | 6-20-91 | HA188 | 80 | 9.70 | 2.025 | 1.008 | 0.126 | 0.246 | 33.20 | 36.2072 | 36.2071 | 0.0001 |
| Generic rf | 6-20-91 | 17-4PH | 35 | 7.80 | 2.010 | 1.008 | 0.063 | 0.255 | 29.21 | 15.0561 | 15.0552 | 0.0009 |
| Generic rf | 6-20-91 | 17-4PH | 36 | 7.80 | 2.003 | 1.010 | 0.061 | 0.258 | 29.03 | 14.6182 | 14.6176 | 0.0006 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) | | |
|-------------|-----------|-------------------|-------------------------------------|---------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|----------|----------|
| | | | | length | width | thick | | | | | | | | | |
| 2 Weeks Old | pH 10.35 | | | | | | | | | | | | | | |
| Generic rf | 6-27-91 | Ni-S | 336 | 8.90 | 2.051 | 1.005 | 0.079 | 0.235 | 30.75 | 22.9244 | 20.6200 | 2.3044 | 1.0 | 3.32E+00 | |
| Generic rf | 6-27-91 | Ni-S | 342 | 8.90 | 2.058 | 1.005 | 0.081 | 0.235 | 32.34 | 24.2107 | 21.9316 | 2.2791 | 1.0 | 3.12E+00 | |
| Generic rf | 6-27-91 | Ni-P*** | 21 | 8.90 | 2.012 | 1.013 | 0.071 | 0.238 | 29.93 | 17.9072 | 0.0069 | 1.0 | 0.02E-02 | 1.00E-02 | |
| Generic rf | 6-27-91 | Ni-P*** | 23 | 8.90 | 2.022 | 1.015 | 0.072 | 0.237 | 30.19 | 18.1208 | 18.1141 | 0.0067 | 1.0 | 9.82E-03 | |
| Generic rf | 6-27-91 | C4340 | 1 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.1143 | 15.1128 | 0.0015 | 24.0 | 4.27E-04 | 2.47E-04 |
| Generic rf | 6-27-91 | C4340 | 2 | 7.84 | 2.008 | 0.989 | 0.063 | 0.253 | 28.68 | 15.0327 | 15.0318 | 0.0009 | 24.0 | 6.57E-05 | |
| Generic rf | 6-27-91 | D6AC | 54 | 8.20 | 2.010 | 0.990 | 0.084 | 0.244 | 30.02 | 19.3027 | 19.3007 | 0.0020 | 24.0 | 1.33E-04 | 1.30E-04 |
| Generic rf | 6-27-91 | D6AC | 55 | 8.20 | 1.997 | 1.003 | 0.082 | 0.249 | 30.05 | 19.8244 | 19.8225 | 0.0019 | 24.0 | 1.22E-04 | |
| Generic rf | 6-27-91 | 316ss | 40 | 8.00 | 2.009 | 1.005 | 0.068 | 0.249 | 29.44 | 13.6957 | 13.6941 | 0.0016 | 24.0 | 1.11E-04 | 1.05E-04 |
| Generic rf | 6-27-91 | 316ss | 45 | 8.00 | 2.006 | 1.003 | 0.067 | 0.245 | 29.31 | 13.9559 | 13.9545 | 0.0014 | 24.0 | 9.80E-05 | |
| Generic rf | 6-27-91 | 410ss | 23 | 7.70 | 2.028 | 1.008 | 0.061 | 0.253 | 29.35 | 14.3020 | 14.3018 | 0.0002 | 24.0 | 1.45E-05 | 4.41E-05 |
| Generic rf | 6-27-91 | 410ss | 24 | 7.70 | 2.012 | 1.006 | 0.059 | 0.256 | 28.94 | 13.8364 | 13.8354 | 0.0010 | 24.0 | 7.36E-05 | |
| Generic rf | 6-27-91 | I-718 | 39 | 8.60 | 2.017 | 1.005 | 0.063 | 0.245 | 29.27 | 16.1705 | 16.1699 | 0.0006 | 24.0 | 3.94E-05 | 4.58E-05 |
| Generic rf | 6-27-91 | I-718 | 40 | 8.60 | 2.002 | 1.007 | 0.063 | 0.246 | 29.12 | 15.7113 | 15.7105 | 0.0008 | 24.0 | 5.24E-05 | |
| Generic rf | 6-27-91 | HA188 | 77 | 9.70 | 1.993 | 1.007 | 0.127 | 0.245 | 32.77 | 36.0178 | 36.0166 | 0.0012 | 24.0 | 6.19E-05 | 6.96E-05 |
| Generic rf | 6-27-91 | HA188 | 78 | 9.70 | 2.008 | 1.002 | 0.127 | 0.245 | 32.86 | 36.0561 | 36.0566 | 0.0015 | 24.0 | 7.72E-05 | |
| Generic rf | 6-27-91 | 17-4PH | 39 | 7.80 | 2.007 | 1.004 | 0.063 | 0.249 | 29.09 | 15.2031 | 15.2022 | 0.0009 | 24.0 | 6.51E-05 | 6.15E-05 |
| Generic rf | 6-27-91 | 17-4PH | 40 | 7.80 | 2.003 | 1.007 | 0.063 | 0.258 | 29.07 | 15.1473 | 15.1481 | 0.0008 | 24.0 | 5.79E-05 | |
| 3 Weeks Old | pH 10.31 | | | | | | | | | | | | | | |
| Generic rf | 7-4-91 | Ni-S | 370 | 8.90 | 2.051 | 1.005 | 0.079 | 0.235 | 30.75 | 22.8313 | 20.5600 | 2.2713 | 1.0 | 3.27E+00 | |
| Generic rf | 7-4-91 | Ni-S | 371 | 8.90 | 2.058 | 1.005 | 0.081 | 0.235 | 32.34 | 22.5993 | 20.4481 | 2.1512 | 1.0 | 2.94E+00 | |
| Generic rf | 7-4-91 | Ni-P*** | 48 | 8.90 | 2.012 | 1.013 | 0.071 | 0.238 | 29.93 | 18.1284 | 18.1225 | 0.0059 | 1.0 | 8.72E-03 | 7.29E-03 |
| Generic rf | 7-4-91 | Ni-P*** | 49 | 8.90 | 2.022 | 1.015 | 0.072 | 0.237 | 30.19 | 18.0009 | 17.9969 | 0.0040 | 1.0 | 5.86E-03 | |
| Generic rf | 7-4-91 | Ni-P* | 24 | 8.90 | 2.019 | 1.014 | 0.076 | 0.235 | 30.36 | 18.9895 | 18.6636 | 0.3259 | 1.0 | 4.73E-01 | 5.01E-01 |
| Generic rf | 7-4-91 | Ni-P* | 34 | 8.90 | 2.033 | 1.013 | 0.073 | 0.235 | 30.35 | 18.5009 | 18.1389 | 0.3620 | 1.0 | 5.28E-01 | |
| Generic rf | 7-4-91 | C4340 | 92 | 7.84 | 1.999 | 1.027 | 0.063 | 0.252 | 29.58 | 15.4755 | 15.4748 | 0.0007 | 24.0 | 1.94E-04 | 1.11E-04 |
| Generic rf | 7-4-91 | C4340 | 93 | 7.84 | 2.002 | 1.021 | 0.062 | 0.250 | 29.41 | 15.2801 | 15.2797 | 0.0004 | 24.0 | 2.85E-05 | |
| Generic rf | 7-4-91 | D6AC | 20 | 8.20 | 2.022 | 0.994 | 0.081 | 0.249 | 30.09 | 19.6105 | 19.6096 | 0.0009 | 24.0 | 5.98E-05 | 5.39E-05 |
| Generic rf | 7-4-91 | D6AC | 21 | 8.20 | 2.012 | 0.962 | 0.082 | 0.250 | 29.14 | 19.1121 | 19.1114 | 0.0007 | 24.0 | 4.81E-05 | |
| Generic rf | 7-4-91 | 316ss | 38 | 8.00 | 2.015 | 1.004 | 0.067 | 0.247 | 29.45 | 13.9140 | 13.9136 | 0.0004 | 24.0 | 2.79E-05 | 3.81E-05 |
| Generic rf | 7-4-91 | 316ss | 39 | 8.00 | 2.022 | 1.010 | 0.068 | 0.250 | 29.75 | 14.0248 | 14.0241 | 0.0007 | 24.0 | 4.82E-05 | |
| Generic rf | 7-4-91 | 410ss | 19 | 7.70 | 2.024 | 1.005 | 0.059 | 0.249 | 29.11 | 13.8917 | 13.8912 | 0.0005 | 24.0 | 3.66E-05 | 3.30E-05 |
| Generic rf | 7-4-91 | 410ss | 20 | 7.70 | 2.008 | 1.007 | 0.059 | 0.253 | 28.93 | 13.8810 | 13.8806 | 0.0004 | 24.0 | 2.95E-05 | |
| Generic rf | 7-4-91 | I-718 | 23 | 8.60 | 2.009 | 1.004 | 0.063 | 0.246 | 29.13 | 16.0139 | 16.0138 | 0.0001 | 24.0 | 6.55E-06 | 1.64E-05 |
| Generic rf | 7-4-91 | I-718 | 24 | 8.60 | 2.009 | 1.001 | 0.063 | 0.246 | 29.05 | 16.0707 | 16.0703 | 0.0004 | 24.0 | 2.63E-05 | |
| Generic rf | 7-4-91 | HA188 | 81 | 9.70 | 2.002 | 1.009 | 0.127 | 0.247 | 32.95 | 36.3060 | 36.3056 | 0.0004 | 24.0 | 2.05E-05 | 2.56E-05 |
| Generic rf | 7-4-91 | HA188 | 82 | 9.70 | 2.019 | 1.006 | 0.127 | 0.243 | 33.13 | 36.3653 | 36.3647 | 0.0006 | 24.0 | 3.06E-05 | |
| Generic rf | 7-4-91 | 17-4PH | 37 | 7.80 | 1.992 | 1.003 | 0.062 | 0.252 | 28.78 | 14.5966 | 14.5965 | 0.0001 | 24.0 | 7.31E-06 | 7.30E-06 |
| Generic rf | 7-4-91 | 17-4PH | 38 | 7.80 | 2.004 | 0.998 | 0.062 | 0.250 | 28.82 | 14.7048 | 14.7047 | 0.0001 | 24.0 | 7.30E-06 | |

| Stripper Material | Coupon Material | Coupon Density (g/cm ³) | Unmasked Dimensions | | | | Initial Area (cm ²) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) | | | |
|----------------------|--------------------|---|---------------------|-------|-------|-------|---------------------------------------|--------------------------|---------------------------|--------------------------|------------------------------|----------------------------|------|-----------|-----------|
| | | | length | width | thick | hole | | | | | | | | | |
| 4 Weeks Old | | | | | | | | | | | | | | | |
| Generic rf | 7-11-91 | Ni-S | 376 | 8.90 | 2.050 | 1.054 | 0.080 | 0.236 | 32.13 | 23.2110 | 21.1122 | 2.0988 | 1.0 | 2.89E+00 | 2.79E+00 |
| Generic rf | 7-11-91 | Ni-S | 356 | 8.90 | 2.047 | 1.041 | 0.077 | 0.235 | 31.56 | 21.7691 | 19.3509 | 1.9182 | 1.0 | 2.69E+00 | |
| Generic rf | 7-11-91 | Ni-P** | 35 | 8.90 | 2.019 | 1.007 | 0.069 | 0.241 | 29.73 | 17.1601 | 17.1569 | 0.0032 | 2.0 | 2.38E-03 | 5.21E-03 |
| Generic rf | 7-11-91 | Ni-P** | 38 | 8.90 | 2.020 | 1.012 | 0.071 | 0.238 | 30.01 | 18.0736 | 18.0627 | 0.0109 | 2.0 | 8.03E-03 | |
| Generic rf | 7-11-91 | Ni-P* | 83 | 8.90 | 2.025 | 1.014 | 0.075 | 0.236 | 30.38 | 19.0305 | 18.1384 | 0.8921 | 2.0 | 6.49E-01 | 6.08E-01 |
| Generic rf | 7-11-91 | Ni-P* | 84 | 8.90 | 2.024 | 1.013 | 0.075 | 0.235 | 30.35 | 18.8395 | 18.9631 | 0.7764 | 2.0 | 5.66E-01 | |
| Generic rf | 7-11-91 | C4340 | 92 | 7.84 | 1.999 | 1.027 | 0.063 | 0.252 | 29.58 | 15.4748 | 15.4747 | 0.0001 | 24.0 | 2.77E-05 | 2.45E-05 |
| Generic rf | 7-11-91 | C4340 | 93 | 7.84 | 2.002 | 1.021 | 0.062 | 0.250 | 29.41 | 15.2797 | 15.2794 | 0.0003 | 24.0 | 2.13E-05 | |
| Generic rf | 7-11-91 | D6AC | 20 | 8.20 | 2.022 | 0.994 | 0.081 | 0.249 | 30.09 | 19.6096 | 19.5994 | 0.0002 | 24.0 | 1.33E-05 | 6.65E-06 |
| Generic rf | 7-11-91 | D6AC | 21 | 8.20 | 2.012 | 0.962 | 0.082 | 0.250 | 29.14 | 19.1114 | 19.1114 | 0.0000 | 24.0 | 0.00E+00 | |
| Generic rf | 7-11-91 | 316ss | 38 | 8.00 | 2.015 | 0.904 | 0.067 | 0.247 | 29.45 | 13.9136 | 13.9137 | -0.0001 | 24.0 | -6.96E-06 | -1.38E-05 |
| Generic rf | 7-11-91 | 316ss | 39 | 8.00 | 2.022 | 1.010 | 0.068 | 0.250 | 29.75 | 14.0241 | 14.0241 | 0.0244 | 24.0 | -2.07E-05 | |
| Generic rf | 7-11-91 | 410ss | 19 | 7.70 | 2.024 | 1.005 | 0.059 | 0.249 | 29.11 | 13.8912 | 13.8907 | 0.0005 | 24.0 | 3.66E-05 | 2.57E-05 |
| Generic rf | 7-11-91 | 410ss | 20 | 7.70 | 2.008 | 1.007 | 0.059 | 0.253 | 28.93 | 13.8806 | 13.8804 | 0.0002 | 24.0 | 1.47E-05 | |
| Generic rf | 7-11-91 | I-718 | 23 | 8.60 | 2.009 | 1.006 | 0.063 | 0.246 | 29.13 | 16.0138 | 16.0138 | 0.0000 | 24.0 | 0.00E+00 | |
| Generic rf | 7-11-91 | I-718 | 24 | 8.60 | 2.009 | 1.001 | 0.063 | 0.246 | 29.45 | 16.0703 | 16.0703 | 0.0000 | 24.0 | 0.00E+00 | |
| Generic rf | 7-11-91 | HA188 | 81 | 9.70 | 2.002 | 1.009 | 0.127 | 0.247 | 32.95 | 36.3056 | 36.3057 | -0.0001 | 24.0 | -5.13E-06 | -1.44E-08 |
| Generic rf | 7-11-91 | HA188 | 82 | 9.70 | 2.019 | 1.006 | 0.127 | 0.243 | 33.13 | 36.3647 | 36.3646 | 0.0001 | 24.0 | 5.10E-06 | |
| Generic rf | 7-11-91 | 17-4PH | 37 | 7.80 | 1.992 | 1.003 | 0.062 | 0.252 | 28.78 | 14.5965 | 14.5965 | 0.0000 | 24.0 | 0.00E+00 | 3.65E-06 |
| Generic rf | 7-11-91 | 17-4PH | 38 | 7.80 | 2.004 | 0.998 | 0.062 | 0.250 | 28.82 | 14.7047 | 14.7046 | 0.0001 | 24.0 | 7.30E-06 | |
| 5 Weeks Old | | | | | | | | | | | | | | | |
| Generic rf | 7-18-91 | Ni-S | 413 | 8.90 | 2.040 | 1.043 | 0.076 | 0.237 | 31.44 | 21.2393 | 19.3524 | 1.8869 | 1.0 | 2.65E+00 | 2.63E+00 |
| Generic rf | 7-18-91 | Ni-S | 416 | 8.90 | 2.057 | 1.055 | 0.079 | 0.237 | 32.20 | 23.3868 | 21.4926 | 1.8942 | 1.0 | 2.60E+00 | |
| Generic rf | 7-18-91 | Ni-P** | 57 | 8.90 | 2.016 | 1.012 | 0.072 | 0.238 | 30.02 | 18.2669 | 18.1718 | 0.0951 | 2.0 | 7.01E-02 | 3.66E-02 |
| Generic rf | 7-18-91 | Ni-P** | 17 | 8.90 | 2.012 | 1.014 | 0.067 | 0.243 | 29.69 | 16.8895 | 16.8895 | 0.0041 | 2.0 | 3.05E-03 | |
| Generic rf | 7-18-91 | Ni-P* | 285 | 8.90 | 2.020 | 1.011 | 0.074 | 0.237 | 30.17 | 18.4985 | 17.9013 | 0.972 | 2.0 | 4.38E-01 | 5.76E-01 |
| Generic rf | 7-18-91 | Ni-P* | 288 | 8.90 | 2.022 | 1.013 | 0.075 | 0.235 | 30.32 | 18.9253 | 17.9464 | 0.9789 | 2.0 | 7.14E-01 | |
| Generic rf | 7-18-91 | C4340 | 66 | 7.84 | 1.999 | 1.025 | 0.062 | 0.253 | 29.46 | 15.1575 | 15.1570 | 0.0005 | 24.0 | 1.39E-04 | 8.03E-05 |
| Generic rf | 7-18-91 | C4340 | 67 | 7.84 | 2.003 | 1.023 | 0.062 | 0.252 | 29.47 | 15.0410 | 15.0407 | 0.0003 | 24.0 | 2.13E-05 | |
| Generic rf | 7-18-91 | D6AC | 8 | 8.20 | 2.015 | 0.999 | 0.058 | 0.250 | 30.30 | 20.6057 | 20.6054 | 0.0003 | 24.0 | 1.08E-05 | 1.64E-05 |
| Generic rf | 7-18-91 | D6AC | 9 | 8.20 | 2.007 | 0.982 | 0.083 | 0.249 | 29.68 | 20.0269 | 20.0267 | 0.0002 | 24.0 | 1.35E-05 | |
| Generic rf | 7-18-91 | 316ss | 26 | 8.00 | 2.025 | 1.006 | 0.067 | 0.250 | 29.57 | 14.0735 | 14.0735 | 0.0002 | 24.0 | 1.39E-05 | -1.38E-05 |
| Generic rf | 7-18-91 | 316ss | 27 | 8.00 | 2.027 | 1.003 | 0.069 | 0.250 | 29.69 | 14.2152 | 14.2153 | -0.0006 | 24.0 | -4.14E-05 | |
| Generic rf | 7-18-91 | 410ss | 7 | 7.70 | 2.027 | 1.002 | 0.058 | 0.255 | 28.98 | 13.8047 | 13.8047 | 0.0000 | 24.0 | 0.00E+00 | 2.56E-05 |
| Generic rf | 7-18-91 | 410ss | 8 | 7.70 | 2.021 | 1.006 | 0.059 | 0.249 | 29.10 | 13.9485 | 13.9478 | 0.0007 | 24.0 | 5.12E-05 | |
| Generic rf | 7-18-91 | I-718 | 11 | 8.60 | 1.985 | 1.004 | 0.062 | 0.246 | 28.74 | 15.5846 | 15.5851 | -0.0005 | 24.0 | -3.32E-05 | -1.66E-05 |
| Generic rf | 7-18-91 | I-718 | 13 | 8.60 | 2.011 | 1.004 | 0.063 | 0.245 | 29.16 | 15.9750 | 15.9750 | 0.0000 | 24.0 | 0.00E+00 | |
| Generic rf | 7-18-91 | HA188 | 12 | 9.70 | 2.020 | 1.006 | 0.126 | 0.247 | 33.08 | 36.1578 | 36.1573 | 0.0005 | 24.0 | 2.56E-05 | 2.57E-05 |
| Generic rf | 7-18-91 | HA188 | 13 | 9.70 | 2.004 | 1.006 | 0.126 | 0.247 | 32.83 | 35.7728 | 35.7723 | 0.0005 | 24.0 | 2.58E-05 | |
| Generic rf | 7-18-91 | 17-4PH | 25 | 7.80 | 1.995 | 1.004 | 0.063 | 0.260 | 28.87 | 14.9068 | 14.9057 | 0.0011 | 24.0 | 8.01E-05 | 1.84E-05 |
| Generic rf | 7-18-91 | 17-4PH | 26 | 7.80 | 2.012 | 1.004 | 0.063 | 0.258 | 29.11 | 15.1640 | 15.1646 | -0.0006 | 24.0 | -4.33E-05 | |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) | |
|-------------|-----------|-------------------|-------------------------------------|---------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|----------|
| | | | | length | width | thick | | | | | | | | |
| 6 Weeks Old | pH 10.10 | | | | | | | | | | | | | |
| Generic rf | 7-25-91 | Ni-S | 405 | 8.90 | 2.063 | 1.062 | 0.083 | 0.230 | 32.75 | 24.4509 | 22.6760 | 1.7749 | 1.0 | 2.40E+00 |
| Generic rf | 7-25-91 | Ni-S | 408 | 8.90 | 2.046 | 1.042 | 0.077 | 0.236 | 31.57 | 21.9839 | 20.1457 | 1.8382 | 1.0 | 2.58E+00 |
| Generic rf | 7-25-91 | Ni-P*** | 69 | 8.90 | 2.021 | 1.016 | 0.072 | 0.234 | 30.21 | 18.2160 | 18.2125 | 0.0035 | 2.0 | 2.56E-03 |
| Generic rf | 7-25-91 | Ni-P** | 70 | 8.90 | 2.019 | 1.009 | 0.068 | 0.239 | 29.73 | 17.1159 | 17.1137 | 0.0022 | 2.0 | 1.64E-03 |
| Generic rf | 7-25-91 | Ni-P* | 192 | 8.90 | 2.002 | 1.017 | 0.074 | 0.235 | 30.09 | 18.4068 | 17.8448 | 0.5620 | 2.0 | 4.13E-01 |
| Generic rf | 7-25-91 | Ni-P* | 205 | 8.90 | 2.007 | 1.014 | 0.075 | 0.235 | 30.14 | 18.4714 | 17.7959 | 0.6755 | 2.0 | 4.96E-01 |
| Generic rf | 7-25-91 | C4340 | 66 | 7.84 | 1.999 | 1.025 | 0.062 | 0.253 | 29.46 | 15.1570 | 15.1564 | 0.0066 | 2.0 | 1.67E-04 |
| Generic rf | 7-25-91 | C4340 | 67 | 7.84 | 2.003 | 1.023 | 0.062 | 0.252 | 29.47 | 15.0407 | 15.0404 | 0.0003 | 2.0 | 9.42E-05 |
| Generic rf | 7-25-91 | D6AC | 8 | 8.20 | 2.015 | 0.999 | 0.084 | 0.250 | 30.30 | 20.6054 | 20.6047 | 0.0007 | 2.0 | 4.00E-05 |
| Generic rf | 7-25-91 | D6AC | 9 | 8.20 | 2.007 | 0.982 | 0.083 | 0.249 | 29.68 | 20.0267 | 20.0262 | 0.0005 | 2.0 | 3.37E-05 |
| Generic rf | 7-25-91 | 316ss | 26 | 8.00 | 2.025 | 1.004 | 0.067 | 0.250 | 29.57 | 14.0735 | 14.0728 | 0.0007 | 2.0 | 4.85E-05 |
| Generic rf | 7-25-91 | 316ss | 27 | 8.00 | 2.027 | 1.003 | 0.069 | 0.250 | 29.69 | 14.2158 | 14.2149 | 0.0009 | 2.0 | 6.22E-05 |
| Generic rf | 7-25-91 | 410ss | 7 | 7.70 | 2.027 | 1.002 | 0.058 | 0.255 | 28.98 | 13.8047 | 13.8040 | 0.0007 | 2.0 | 5.15E-05 |
| Generic rf | 7-25-91 | 410ss | 8 | 7.70 | 2.021 | 1.006 | 0.059 | 0.249 | 29.10 | 13.9478 | 13.9474 | 0.0004 | 2.0 | 2.93E-05 |
| Generic rf | 7-25-91 | I-718 | 11 | 8.60 | 1.985 | 1.004 | 0.062 | 0.246 | 28.74 | 15.5851 | 15.5842 | 0.0009 | 2.0 | 5.97E-05 |
| Generic rf | 7-25-91 | I-718 | 13 | 8.60 | 2.011 | 1.004 | 0.063 | 0.245 | 29.16 | 15.9750 | 15.9745 | 0.0005 | 2.0 | 3.27E-05 |
| Generic rf | 7-25-91 | HA188 | 12 | 9.70 | 2.020 | 1.006 | 0.126 | 0.247 | 33.08 | 36.1573 | 36.1569 | 0.0004 | 2.0 | 2.05E-05 |
| Generic rf | 7-25-91 | HA188 | 13 | 9.70 | 2.004 | 1.006 | 0.126 | 0.247 | 32.83 | 35.7723 | 35.7719 | 0.0004 | 2.0 | 2.06E-05 |
| Generic rf | 7-25-91 | 17-4PH | 25 | 7.80 | 1.995 | 1.004 | 0.063 | 0.260 | 28.87 | 14.9057 | 14.9051 | 0.0006 | 2.0 | 4.37E-05 |
| Generic rf | 7-25-91 | 17-4PH | 26 | 7.80 | 2.012 | 1.004 | 0.063 | 0.258 | 29.11 | 15.1666 | 15.1634 | 0.0012 | 2.0 | 6.52E-05 |
| 7 Weeks Old | pH 9.94 | | | | | | | | | | | | | |
| Generic rf | 8-1-91 | Ni-S | 414 | 8.90 | 2.045 | 1.052 | 0.077 | 0.236 | 31.82 | 22.2561 | 20.5114 | 1.7427 | 1.0 | 2.42E+00 |
| Generic rf | 8-1-91 | Ni-S | 426 | 8.90 | 2.046 | 1.047 | 0.078 | 0.237 | 31.76 | 22.9378 | 21.2237 | 1.7141 | 1.0 | 2.39E+00 |
| Generic rf | 8-1-91 | Ni-P*** | 73 | 8.90 | 2.027 | 1.021 | 0.072 | 0.238 | 30.41 | 18.1533 | 18.1481 | 0.0052 | 2.0 | 3.78E-03 |
| Generic rf | 8-1-91 | Ni-P** | 78 | 8.90 | 2.013 | 1.014 | 0.072 | 0.238 | 30.03 | 18.0470 | 18.0389 | 0.0081 | 2.0 | 5.97E-03 |
| Generic rf | 8-1-91 | Ni-P* | 65 | 8.90 | 2.019 | 1.019 | 0.076 | 0.235 | 30.36 | 19.1489 | 19.2413 | 0.9076 | 2.0 | 6.61E-01 |
| Generic rf | 8-1-91 | Ni-P* | 66 | 8.90 | 2.022 | 1.012 | 0.075 | 0.234 | 30.30 | 18.9328 | 18.0838 | 0.8469 | 2.0 | 6.20E-01 |
| Generic rf | 8-1-91 | C4340 | 3 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.0690 | 15.0684 | 0.0006 | 2.0 | 4.38E-05 |
| Generic rf | 8-1-91 | C4340 | 4 | 7.84 | 2.008 | 0.989 | 0.063 | 0.253 | 28.68 | 15.1078 | 15.1074 | 0.0004 | 2.0 | 2.92E-05 |
| Generic rf | 8-1-91 | D6AC | 46 | 8.20 | 2.003 | 0.992 | 0.082 | 0.248 | 29.84 | 20.0803 | 20.0794 | 0.0009 | 2.0 | 6.03E-05 |
| Generic rf | 8-1-91 | D6AC | 53 | 8.20 | 1.970 | 1.004 | 0.096 | 0.245 | 29.44 | 20.3587 | 20.3581 | 0.0006 | 2.0 | 4.08E-05 |
| Generic rf | 8-1-91 | 316ss | 26 | 8.00 | 2.025 | 1.004 | 0.067 | 0.250 | 29.57 | 14.0728 | 14.0726 | 0.0002 | 2.0 | 1.39E-05 |
| Generic rf | 8-1-91 | 316ss | 27 | 8.00 | 2.027 | 1.003 | 0.069 | 0.250 | 29.69 | 14.2149 | 14.2144 | 0.0005 | 2.0 | 3.45E-05 |
| Generic rf | 8-1-91 | 410ss | 21 | 7.70 | 2.023 | 1.003 | 0.059 | 0.253 | 29.03 | 13.9886 | 13.9858 | 0.0008 | 2.0 | 5.87E-05 |
| Generic rf | 8-1-91 | 410ss | 22 | 7.70 | 2.012 | 1.005 | 0.060 | 0.254 | 28.98 | 13.7056 | 13.7056 | 0.0010 | 2.0 | 7.35E-05 |
| Generic rf | 8-1-91 | I-718 | 37 | 8.60 | 2.011 | 1.003 | 0.063 | 0.246 | 29.13 | 16.1780 | 16.1774 | 0.0006 | 2.0 | 3.93E-05 |
| Generic rf | 8-1-91 | I-718 | 38 | 8.60 | 2.019 | 1.002 | 0.063 | 0.243 | 29.23 | 16.0123 | 16.0119 | 0.0004 | 2.0 | 2.61E-05 |
| Generic rf | 8-1-91 | HA188 | 12 | 9.70 | 2.020 | 1.006 | 0.126 | 0.245 | 33.08 | 36.1569 | 36.1565 | 0.0004 | 2.0 | 2.05E-05 |
| Generic rf | 8-1-91 | HA188 | 13 | 9.70 | 2.004 | 1.004 | 0.063 | 0.260 | 28.87 | 14.9051 | 14.9052 | -0.0001 | 2.0 | 1.03E-05 |
| Generic rf | 8-1-91 | 17-4PH | 25 | 7.80 | 1.995 | 1.004 | 0.064 | 0.258 | 29.11 | 15.1634 | 15.1628 | 0.0006 | 2.0 | 4.33E-05 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Initial Area (cm ²) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|-------------------|-------------------------------------|---------------------|-------|-------|---------------------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | Length | width | thick | | | | | | |
| 8 Weeks Old after regeneration with 2.5L EN pH 10.26 | | | | | | | | | | | | |
| Generic rf | 8-8-91 | Mi-S | 390 | 8.90 | 2.058 | 1.045 | 0.078 | 0.239 | 31.87 | 22.3081 | 20.6093 | 1.6988 |
| Generic rf | 8-8-91 | Mi-S | 395 | 8.90 | 2.06 | 1.043 | 0.027 | 0.237 | 28.58 | 21.7114 | 20.0619 | 1.0 |
| Generic rf | 8-8-91 | Mi-puu | 92 | 8.90 | 2.021 | 1.012 | 0.075 | 0.238 | 30.26 | 18.0665 | 18.0617 | 0.0048 |
| Generic rf | 8-8-91 | Mi-puu | 93 | 8.90 | 2.014 | 1.010 | 0.071 | 0.236 | 29.88 | 17.9511 | 17.9313 | 0.0198 |
| Generic rf | 8-8-91 | Mi-P* | 130 | 8.90 | 2.017 | 0.989 | 0.073 | 0.236 | 29.48 | 18.0035 | 17.3377 | 0.0658 |
| Generic rf | 8-8-91 | Mi-P* | 276 | 8.90 | 2.013 | 1.011 | 0.073 | 0.237 | 30.01 | 18.3674 | 17.5498 | 0.8176 |
| Generic rf | 8-8-91 | C4340 | 7 | 7.84 | 2.008 | 0.986 | 0.062 | 0.250 | 28.56 | 15.0944 | 15.0933 | 0.0011 |
| Generic rf | 8-8-91 | C4340 | 8 | 7.84 | 2.005 | 0.988 | 0.063 | 0.250 | 28.63 | 15.0759 | 15.0751 | 0.0008 |
| Generic rf | 8-8-91 | D6AC | 47 | 8.20 | 2.007 | 0.960 | 0.080 | 0.245 | 28.93 | 18.7688 | 18.7679 | 0.0009 |
| Generic rf | 8-8-91 | D6AC | 48 | 8.20 | 1.988 | 0.985 | 0.084 | 0.245 | 29.58 | 20.2605 | 20.2597 | 0.0008 |
| Generic rf | 8-8-91 | 316ss | 50 | 8.00 | 2.016 | 1.006 | 0.068 | 0.249 | 29.51 | 13.7732 | 13.7725 | 0.0007 |
| Generic rf | 8-8-91 | 316ss | 51 | 8.00 | 2.008 | 1.015 | 0.058 | 0.248 | 29.70 | 13.8413 | 13.8414 | -0.0001 |
| Generic rf | 8-8-91 | 410ss | 27 | 7.70 | 2.023 | 1.009 | 0.059 | 0.253 | 29.19 | 13.9585 | 13.9579 | 0.0006 |
| Generic rf | 8-8-91 | 410ss | 28 | 7.70 | 2.023 | 1.005 | 0.060 | 0.257 | 29.12 | 13.9814 | 13.9805 | 0.0009 |
| Generic rf | 8-8-91 | 1-718 | 35 | 8.60 | 2.022 | 1.008 | 0.063 | 0.245 | 29.37 | 16.0597 | 16.0590 | 0.0007 |
| Generic rf | 8-8-91 | 1-718 | 36 | 8.60 | 2.012 | 1.003 | 0.063 | 0.245 | 29.15 | 15.9142 | 15.9135 | 0.0007 |
| Generic rf | 8-8-91 | HA188 | 75 | 9.70 | 2.026 | 1.003 | 0.126 | 0.245 | 33.08 | 35.7724 | 35.7718 | 0.0006 |
| Generic rf | 8-8-91 | HA188 | 76 | 9.70 | 2.011 | 1.006 | 0.127 | 0.241 | 33.03 | 36.1222 | 36.1217 | 0.0005 |
| Generic rf | 8-8-91 | 17-PH | 67 | 7.80 | 1.994 | 1.001 | 0.063 | 0.258 | 28.78 | 15.2082 | 15.2079 | 0.0003 |
| Generic rf | 8-8-91 | 17-4PH | 68 | 7.80 | 1.999 | 1.004 | 0.061 | 0.260 | 28.80 | 14.5448 | 14.5440 | 0.0008 |
| | | | | | | | | | | | | 24.0 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions - in inches - | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|-------------------|-------------------------------------|-----------------------------------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| Loading Tests Re-Formulation: EN 20Xv, Na m-NBS 10XW, HNO₃ 7Xv, NaSCN 0.1%w First Loading Test (0.94 oz/gal Ni) | | | | | | | | | | | |
| Generic rf 6-20-91 Ni-S | | | | | | | | | | | |
| Generic rf | 6-20-91 | Ni-S | 331 | 8.90 | 2.034 | 1.036 | 0.075 | 0.237 | 31.10 | 20.8495 | 1.6653 |
| Generic rf | 6-20-91 | Ni-S | 333 | 8.90 | 2.052 | 1.037 | 0.075 | 0.239 | 31.38 | 21.3875 | 1.5406 |
| Generic rf | 6-20-91 | Ni-P*** | 13 | 8.90 | 2.024 | 1.014 | 0.072 | 0.238 | 30.18 | 18.3306 | 1.8-3266 |
| Generic rf | 6-20-91 | Ni-P*** | 14 | 8.90 | 2.004 | 1.026 | 0.068 | 0.244 | 29.76 | 16.7585 | 1.6-7563 |
| Generic rf | 6-20-91 | C-340 | 92 | 7.84 | 1.999 | 1.027 | 0.063 | 0.252 | 29.58 | 15.4758 | 15.4753 |
| Generic rf | 6-20-91 | C-340 | 93 | 7.84 | 2.002 | 1.021 | 0.062 | 0.250 | 29.41 | 15.2803 | 15.2798 |
| Generic rf | 6-20-91 | D6AC | 20 | 8.20 | 2.022 | 0.994 | 0.081 | 0.249 | 30.99 | 19.6108 | 19.6103 |
| Generic rf | 6-20-91 | D6AC | 21 | 8.20 | 2.012 | 0.962 | 0.082 | 0.250 | 29.14 | 19.1122 | 19.1121 |
| Generic rf | 6-20-91 | D6AC | 316ss | 8.00 | 2.015 | 1.004 | 0.067 | 0.247 | 29.45 | 13.9141 | 13.9136 |
| Generic rf | 6-20-91 | 316ss | 39 | 8.00 | 2.022 | 1.010 | 0.068 | 0.250 | 29.75 | 14.0253 | 14.0243 |
| Generic rf | 6-20-91 | 410ss | 19 | 7.70 | 2.024 | 1.005 | 0.059 | 0.249 | 29.11 | 13.8920 | 13.8914 |
| Generic rf | 6-20-91 | 410ss | 20 | 7.70 | 2.008 | 1.007 | 0.059 | 0.253 | 28.93 | 13.8814 | 13.8806 |
| Generic rf | 6-20-91 | 1-718 | 23 | 8.60 | 2.009 | 1.004 | 0.063 | 0.246 | 29.13 | 16.0139 | 16.0137 |
| Generic rf | 6-20-91 | 1-718 | 24 | 8.60 | 2.009 | 1.001 | 0.063 | 0.246 | 29.05 | 16.0705 | 16.0704 |
| Generic rf | 6-20-91 | HA188 | 81 | 9.70 | 2.002 | 1.009 | 0.127 | 0.247 | 32.95 | 36.3061 | 36.3056 |
| Generic rf | 6-20-91 | HA188 | 82 | 9.70 | 2.019 | 1.006 | 0.127 | 0.243 | 33.13 | 36.3653 | 36.3646 |
| Generic rf | 6-20-91 | 117-4PH | 37 | 7.80 | 1.992 | 1.003 | 0.062 | 0.252 | 28.78 | 14.5970 | 14.5964 |
| Generic rf | 6-20-91 | 117-4PH | 38 | 7.80 | 2.004 | 0.998 | 0.082 | 0.250 | 28.82 | 14.7049 | 14.7045 |
| 2nd Loading Test (2.01 oz/gal Ni) pH 10.38 | | | | | | | | | | | |
| Generic rf | 6-25-91 | Ni-S | 389 | 8.90 | 2.080 | 1.068 | 0.092 | 0.233 | 33.71 | 26.8913 | 25.4380 |
| Generic rf | 6-25-91 | Ni-S | 449 | 8.90 | 2.068 | 1.056 | 0.088 | 0.236 | 32.94 | 25.2518 | 24.1041 |
| Generic rf | 6-25-91 | Ni-P*** | 18 | 8.90 | 2.023 | 1.015 | 0.072 | 0.236 | 30.20 | 18.3199 | 18.3093 |
| Generic rf | 6-25-91 | Ni-P*** | 19 | 8.90 | 2.020 | 1.014 | 0.071 | 0.237 | 30.07 | 18.0547 | 18.0495 |
| Generic rf | 6-25-91 | C-340 | 49 | 7.84 | 2.007 | 1.021 | 0.062 | 0.249 | 29.48 | 15.2634 | 15.2632 |
| Generic rf | 6-25-91 | C-340 | 91 | 7.84 | 2.004 | 1.024 | 0.062 | 0.251 | 29.51 | 15.2540 | 15.2537 |
| Generic rf | 6-25-91 | D6AC | 18 | 8.20 | 2.008 | 0.998 | 0.079 | 0.253 | 29.87 | 19.2191 | 19.2192 |
| Generic rf | 6-25-91 | D6AC | 19 | 8.20 | 2.017 | 0.993 | 0.084 | 0.249 | 30.17 | 20.1041 | 20.1042 |
| Generic rf | 6-25-91 | 316ss | 36 | 8.00 | 2.011 | 1.005 | 0.068 | 0.251 | 29.46 | 14.0116 | 14.0115 |
| Generic rf | 6-25-91 | 316ss | 37 | 8.00 | 2.029 | 1.006 | 0.068 | 0.250 | 29.74 | 14.0116 | 14.0119 |
| Generic rf | 6-25-91 | 410ss | 17 | 7.70 | 2.008 | 1.005 | 0.059 | 0.256 | 28.86 | 14.1251 | 14.1253 |
| Generic rf | 6-25-91 | 410ss | 18 | 7.70 | 2.011 | 1.008 | 0.059 | 0.254 | 28.99 | 13.8062 | 13.8061 |
| Generic rf | 6-25-91 | 1-718 | 21 | 8.60 | 2.023 | 1.005 | 0.063 | 0.245 | 29.36 | 15.9788 | 15.9794 |
| Generic rf | 6-25-91 | 1-718 | 22 | 8.60 | 2.003 | 1.004 | 0.062 | 0.244 | 29.00 | 15.7561 | 15.7564 |
| Generic rf | 6-25-91 | HA188 | 79 | 9.70 | 2.003 | 1.012 | 0.127 | 0.245 | 33.05 | 36.2774 | 36.2781 |
| Generic rf | 6-25-91 | HA188 | 80 | 9.70 | 2.025 | 1.008 | 0.126 | 0.246 | 33.20 | 36.2071 | 36.2075 |
| Generic rf | 6-25-91 | 117-4PH | 35 | 7.80 | 2.010 | 1.008 | 0.063 | 0.255 | 29.21 | 15.0552 | 15.0552 |
| Generic rf | 6-25-91 | 117-4PH | 36 | 7.80 | 2.003 | 1.010 | 0.061 | 0.258 | 29.03 | 14.6176 | 14.6175 |

| Stripper | Test Date | Coupon Material # | | | Coupon Density (g/cm ³) | | | Unmasked Dimensions In inches | | | Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|-------------------|-------|-----------|-------------------------------------|-------|-----------|----------------------------------|---------|-----------|-------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | Length | Width | Thickness | Length | Width | Thickness | Length | Width | Thickness | | | | | | | |
| 3rd Loading Test (2.68 oz/gal Ni) pH 10.34 | | | | | | | | | | | | | | | | | |
| Generic rf | 7-4-91 | Ni-S | 401 | 8.90 | 2.050 | 1.048 | 0.079 | 0.235 | 31.91 | 22.9033 | 22.0395 | 0.8638 | 1.0 | 1.20E+00 | 1.22E+00 | | |
| Generic rf | 7-4-91 | Ni-S | 409 | 8.90 | 2.057 | 1.051 | 0.081 | 0.236 | 32.21 | 23.9094 | 23.0020 | 0.9074 | 1.0 | 1.25E+00 | | | |
| Generic rf | 7-4-91 | Ni-P*** | 52 | 8.90 | 2.019 | 1.013 | 0.072 | 0.238 | 30.08 | 17.9928 | 17.9841 | 0.0887 | 1.0 | 1.28E+02 | 9.49E-03 | | |
| Generic rf | 7-4-91 | Ni-P*** | 53 | 8.90 | 2.016 | 1.014 | 0.072 | 0.238 | 30.07 | 18.1112 | 18.1070 | 0.0042 | 1.0 | 6.18E-03 | | | |
| Generic rf | 7-4-91 | C4340 | 9 | 7.84 | 2.007 | 0.987 | 0.062 | 0.253 | 28.56 | 15.0768 | 15.0767 | 0.0001 | 24.0 | 2.86E-05 | 6.99E-06 | | |
| Generic rf | 7-4-91 | C4340 | 10 | 7.84 | 2.007 | 0.986 | 0.062 | 0.249 | 28.55 | 14.9848 | 14.9850 | -0.0002 | 24.0 | -1.47E-05 | | | |
| Generic rf | 7-4-91 | D6AC | 42 | 8.20 | 2.023 | 0.999 | 0.080 | 0.250 | 30.18 | 19.5463 | 19.5462 | 0.0001 | 24.0 | 6.63E-06 | 4.01E-05 | | |
| Generic rf | 7-4-91 | D6AC | 43 | 8.20 | 2.007 | 1.000 | 0.079 | 0.247 | 29.94 | 19.2179 | 19.2168 | 0.0011 | 24.0 | 7.35E-05 | | | |
| Generic rf | 7-4-91 | 310ss | 52 | 8.00 | 2.027 | 1.006 | 0.068 | 0.250 | 29.71 | 13.8846 | 13.8846 | 0.0000 | 24.0 | 0.00E+00 | 0.00E+00 | | |
| Generic rf | 7-4-91 | 310ss | 53 | 8.00 | 2.013 | 1.011 | 0.068 | 0.255 | 29.63 | 14.1481 | 14.1481 | 0.0000 | 24.0 | 0.00E+00 | 0.00E+00 | | |
| Generic rf | 7-4-91 | 410ss | 29 | 7.70 | 2.026 | 1.006 | 0.061 | 0.253 | 29.27 | 14.0379 | 14.0371 | 0.0008 | 24.0 | 5.82E-05 | 3.64E-05 | | |
| Generic rf | 7-4-91 | 410ss | 30 | 7.70 | 2.032 | 1.007 | 0.060 | 0.249 | 29.34 | 13.9261 | 13.9259 | 0.0002 | 24.0 | 1.45E-05 | | | |
| Generic rf | 7-4-91 | I-718 | 31 | 8.60 | 1.013 | 1.000 | 0.063 | 0.245 | 15.37 | 16.1602 | 16.1601 | 0.0001 | 24.0 | 1.24E-05 | 6.20E-06 | | |
| Generic rf | 7-4-91 | I-718 | 32 | 8.60 | 2.016 | 1.003 | 0.063 | 0.246 | 29.20 | 16.1471 | 16.1471 | 0.0000 | 24.0 | 0.00E+00 | 0.00E+00 | | |
| Generic rf | 7-4-91 | HA188 | 26 | 9.70 | 1.993 | 1.005 | 0.125 | 0.246 | 32.59 | 35.2773 | -0.0002 | 24.0 | -1.04E-05 | -1.44E-05 | | | |
| Generic rf | 7-4-91 | HA188 | 27 | 9.70 | 1.006 | 0.126 | 0.245 | 18.27 | 35.9046 | 35.9048 | -0.0002 | 24.0 | -1.85E-05 | | | | |
| Generic rf | 7-4-91 | 17-4PH | 43 | 7.80 | 2.011 | 1.009 | 0.063 | 0.259 | 29.23 | 15.1814 | 15.1810 | 0.0004 | 24.0 | 2.88E-05 | 1.80E-05 | | |
| Generic rf | 7-4-91 | 17-4PH | 44 | 7.80 | 1.995 | 1.009 | 0.062 | 0.260 | 28.94 | 14.7170 | 14.7169 | 0.0001 | 24.0 | 7.27E-06 | | | |
| 4th Loading Test (4.02 oz/gal Ni) pH 10.30 | | | | | | | | | | | | | | | | | |
| Generic rf | 7-15-91 | Ni-S | 613 | 8.90 | 2.051 | 1.053 | 0.079 | 0.234 | 32.07 | 22.4038 | 21.9526 | 0.4512 | 1.0 | 6.22E-01 | 6.30E-01 | | |
| Generic rf | 7-15-91 | Ni-S | 416 | 8.90 | 2.042 | 1.043 | 0.077 | 0.235 | 31.54 | 21.9291 | 21.4746 | 0.4545 | 1.0 | 6.37E-01 | | | |
| Generic rf | 7-15-91 | Ni-P*** | 54 | 8.90 | 2.024 | 1.014 | 0.072 | 0.236 | 30.19 | 18.1420 | 18.1341 | 0.0079 | 2.0 | 5.79E-03 | 4.58E-03 | | |
| Generic rf | 7-15-91 | Ni-P*** | 55 | 8.90 | 2.016 | 1.019 | 0.072 | 0.236 | 30.21 | 18.2302 | 18.2256 | 0.0046 | 2.0 | 3.37E-03 | | | |
| Generic rf | 7-15-91 | Ni-P* | 242 | 8.90 | 2.024 | 1.014 | 0.075 | 0.236 | 30.37 | 18.9200 | 18.6610 | 0.2590 | 2.0 | 1.09E-01 | 1.72E-01 | | |
| Generic rf | 7-15-91 | Ni-P* | 248 | 8.90 | 2.004 | 1.005 | 0.074 | 0.236 | 30.06 | 18.0192 | 18.3083 | 0.2109 | 2.0 | 1.55E-01 | | | |
| Generic rf | 7-15-91 | C4340 | 66 | 7.84 | 1.999 | 1.025 | 0.072 | 0.253 | 29.46 | 15.1585 | 15.1575 | 0.0010 | 24.0 | 2.79E-04 | 1.46E-04 | | |
| Generic rf | 7-15-91 | C4340 | 67 | 7.84 | 2.003 | 1.023 | 0.062 | 0.252 | 29.47 | 15.0412 | 15.0410 | 0.0002 | 26.0 | 1.42E-05 | | | |
| Generic rf | 7-15-91 | D6AC | 8 | 8.20 | 2.015 | 0.999 | 0.084 | 0.250 | 30.30 | 20.6075 | 20.6057 | 0.0018 | 24.0 | 1.19E-04 | 8.97E-05 | | |
| Generic rf | 7-15-91 | D6AC | 9 | 8.20 | 2.007 | 0.982 | 0.083 | 0.249 | 29.68 | 20.0278 | 20.0269 | 0.0009 | 26.0 | 6.07E-05 | | | |
| Generic rf | 7-15-91 | 310ss | 26 | 8.00 | 2.025 | 1.004 | 0.067 | 0.250 | 29.57 | 14.0737 | 14.0737 | 0.0000 | 26.0 | 0.00E+00 | 2.42E-05 | | |
| Generic rf | 7-15-91 | 310ss | 27 | 8.00 | 2.027 | 1.003 | 0.069 | 0.250 | 29.69 | 14.2152 | 14.2152 | 0.0007 | 26.0 | 4.83E-05 | | | |
| Generic rf | 7-15-91 | 410ss | 7 | 7.70 | 2.027 | 1.002 | 0.058 | 0.255 | 28.98 | 13.8051 | 13.8047 | 0.0004 | 26.0 | 2.94E-05 | 1.84E-05 | | |
| Generic rf | 7-15-91 | 410ss | 8 | 7.70 | 2.021 | 1.006 | 0.059 | 0.249 | 29.10 | 13.9486 | 13.9485 | 0.0001 | 26.0 | 7.32E-06 | | | |
| Generic rf | 7-15-91 | I-718 | 11 | 8.60 | 1.985 | 1.004 | 0.062 | 0.246 | 28.74 | 15.5852 | 15.5846 | 0.0006 | 24.0 | 3.98E-05 | 3.30E-05 | | |
| Generic rf | 7-15-91 | I-718 | 13 | 8.60 | 2.011 | 1.004 | 0.063 | 0.245 | 29.16 | 15.9754 | 15.9750 | 0.0004 | 24.0 | 2.62E-05 | | | |
| Generic rf | 7-15-91 | HA188 | 12 | 9.70 | 2.020 | 1.006 | 0.126 | 0.245 | 33.08 | 36.1582 | 36.1578 | 0.0004 | 24.0 | 2.05E-05 | 1.80E-05 | | |
| Generic rf | 7-15-91 | HA188 | 13 | 9.70 | 2.004 | 1.006 | 0.126 | 0.247 | 32.83 | 35.7751 | 35.7728 | 0.0003 | 24.0 | 1.55E-05 | | | |
| Generic rf | 7-15-91 | 17-4PH | 25 | 7.80 | 1.995 | 1.004 | 0.063 | 0.260 | 28.87 | 14.9072 | 14.9068 | 0.0004 | 24.0 | 2.91E-05 | 4.71E-05 | | |
| Generic rf | 7-15-91 | 17-4PH | 26 | 7.80 | 2.012 | 1.004 | 0.063 | 0.258 | 29.11 | 15.1649 | 15.1640 | 0.0009 | 24.0 | 6.50E-05 | | | |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions length in inches | width | thickness | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) | | |
|--|-----------|-------------------|-------------------------------------|---|-------|-----------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|-----------|-----------|
| Regeneration Tests | | | | | | | | | | | | | | | |
| First Test With 2L EN and 2.5%w Na m-NBS added to 15 gallon solution of 4 oz/gal loaded nickel stripper | | | | | | | | | | | | | | | |
| Generic rf | 7-22-91 | Ni-S | 337 | 8.90 | 2.043 | 1.061 | 0.076 | 0.237 | 31.43 | 21.8891 | 21.0635 | 0.8256 | 1.0 | 1.16E+00 | |
| Generic rf | 7-22-91 | Ni-S | 351 | 8.90 | 2.036 | 1.040 | 0.076 | 0.236 | 31.31 | 21.3092 | 21.3467 | 0.9625 | 1.0 | 1.36E+00 | |
| Generic rf | 7-22-91 | Ni-P*** | 28 | 8.90 | 2.021 | 1.012 | 0.071 | 0.237 | 30.03 | 17.9713 | 0.0081 | 2.0 | 5.97E-03 | 3.84E-03 | |
| Generic rf | 7-22-91 | Ni-P*** | 29 | 8.90 | 2.021 | 1.009 | 0.067 | 0.239 | 29.70 | 16.8999 | 16.8976 | 0.0023 | 2.0 | 1.71E-03 | |
| Generic rf | 7-22-91 | Ni-P* | 267 | 8.90 | 2.023 | 1.012 | 0.075 | 0.236 | 30.30 | 18.6346 | 18.3096 | 0.3340 | 2.0 | 2.44E-01 | 2.48E-01 |
| Generic rf | 7-22-91 | Ni-P* | 277 | 8.90 | 2.023 | 1.012 | 0.076 | 0.236 | 30.36 | 18.7999 | 18.4536 | 0.3463 | 2.0 | 2.52E-01 | |
| Generic rf | 7-22-91 | C340 | 3 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.0700 | 15.0695 | 0.0005 | 24.0 | 1.42E-04 | 8.58E-05 |
| Generic rf | 7-22-91 | C340 | 4 | 7.84 | 2.008 | 0.989 | 0.063 | 0.253 | 28.58 | 15.1087 | 15.1083 | 0.0004 | 24.0 | 2.92E-05 | |
| Generic rf | 7-22-91 | D6AC | 46 | 8.20 | 2.003 | 0.992 | 0.082 | 0.248 | 29.84 | 20.0814 | 20.0809 | 0.0005 | 24.0 | 3.35E-05 | 4.39E-05 |
| Generic rf | 7-22-91 | D6AC | 53 | 8.20 | 1.970 | 0.996 | 0.081 | 0.245 | 29.44 | 20.3602 | 20.3594 | 0.0008 | 24.0 | 5.44E-05 | |
| Generic rf | 7-22-91 | 316SS | 46 | 8.00 | 2.014 | 1.004 | 0.067 | 0.247 | 29.43 | 13.8756 | 13.8755 | 0.0001 | 24.0 | 6.97E-06 | 3.48E-06 |
| Generic rf | 7-22-91 | 316SS | 47 | 8.00 | 2.022 | 2.011 | 0.069 | 0.256 | 56.78 | 14.1215 | 14.1215 | 0.0000 | 24.0 | 0.00E+00 | |
| Generic rf | 7-22-91 | 410SS | 21 | 7.70 | 2.023 | 1.003 | 0.059 | 0.253 | 29.03 | 13.9882 | 13.9880 | 0.0002 | 24.0 | 1.47E-05 | |
| Generic rf | 7-22-91 | 410SS | 22 | 7.70 | 2.012 | 1.005 | 0.060 | 0.254 | 28.98 | 13.7082 | 13.7080 | 0.0002 | 24.0 | 1.47E-05 | |
| Generic rf | 7-22-91 | I-718 | 37 | 8.60 | 2.011 | 1.003 | 0.063 | 0.246 | 29.13 | 16.1786 | 16.1783 | 0.0003 | 24.0 | 1.96E-05 | 6.56E-06 |
| Generic rf | 7-22-91 | I-718 | 38 | 8.60 | 2.019 | 1.002 | 0.063 | 0.243 | 29.23 | 16.0127 | 16.0128 | -0.0001 | 24.0 | -6.53E-06 | |
| Generic rf | 7-22-91 | HA188 | 83 | 9.70 | 1.016 | 1.007 | 0.127 | 0.245 | 18.48 | 35.9879 | 35.9876 | 0.0003 | 24.0 | 2.75E-05 | 1.89E-05 |
| Generic rf | 7-22-91 | HA188 | 84 | 9.70 | 2.007 | 1.002 | 0.127 | 0.245 | 32.84 | 35.9361 | 35.9359 | 0.0002 | 24.0 | 1.03E-05 | |
| Generic rf | 7-22-91 | 17-4PH | 41 | 7.80 | 2.003 | 1.007 | 0.062 | 0.271 | 28.94 | 14.8019 | 14.8022 | -0.0003 | 24.0 | -2.18E-05 | -1.09E-05 |
| Generic rf | 7-22-91 | 17-4PH | 42 | 7.80 | 2.014 | 1.005 | 0.063 | 0.249 | 29.21 | 15.3070 | 15.3070 | 0.0000 | 24.0 | 0.00E+00 | |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions length in inches | width | thickness | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) | | |
|--|-----------|-------------------|-------------------------------------|---|-------|-----------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|----------|----------|
| Second Regeneration with another 2.5%w Na m-NBS added | | | | | | | | | | | | | | | |
| Regeneration Tests | | | | | | | | | | | | | | | |
| Generic rf | 7-24-91 | Ni-S | 346 | 8.90 | 2.050 | 1.037 | 0.076 | 0.239 | 31.41 | 21.5354 | 20.5395 | 0.9959 | 1.0 | 1.40E+00 | |
| Generic rf | 7-24-91 | Ni-S | 350 | 8.90 | 2.065 | 1.064 | 0.083 | 0.233 | 32.83 | 25.3757 | 24.3593 | 1.0164 | 1.0 | 1.37E+00 | |
| Generic rf | 7-24-91 | Ni-P*** | 63 | 8.90 | 2.018 | 1.010 | 0.071 | 0.233 | 29.95 | 17.9673 | 17.9664 | 0.0049 | 2.0 | 5.09E-03 | 3.26E-03 |
| Generic rf | 7-24-91 | Ni-P*** | 64 | 8.90 | 1.995 | 1.010 | 0.068 | 0.244 | 29.40 | 16.7983 | 16.7964 | 0.0019 | 2.0 | 1.43E-03 | |
| Generic rf | 7-24-91 | Ni-P* | 294 | 8.90 | 2.024 | 1.063 | 0.076 | 0.236 | 31.76 | 18.8434 | 18.4365 | 0.4069 | 2.0 | 2.83E-01 | 2.66E-01 |
| Generic rf | 7-24-91 | Ni-P* | 299 | 8.90 | 2.021 | 1.012 | 0.075 | 0.237 | 30.27 | 18.3297 | 17.9882 | 0.3415 | 2.0 | 2.50E-01 | |
| Generic rf | 7-24-91 | C340 | 3 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.0695 | 15.0692 | 0.0003 | 24.0 | 8.55E-05 | 5.00E-05 |
| Generic rf | 7-24-91 | C340 | 4 | 7.84 | 2.008 | 0.989 | 0.063 | 0.253 | 28.68 | 15.1083 | 15.1081 | 0.0002 | 24.0 | 1.46E-05 | |
| Generic rf | 7-24-91 | D6AC | 46 | 8.20 | 2.003 | 0.992 | 0.082 | 0.248 | 29.84 | 20.0809 | 20.0807 | 0.0002 | 24.0 | 1.34E-05 | 1.35E-05 |
| Generic rf | 7-24-91 | D6AC | 53 | 8.20 | 1.970 | 0.996 | 0.081 | 0.245 | 29.44 | 20.3594 | 20.3592 | 0.0002 | 24.0 | 1.36E-05 | |
| Generic rf | 7-24-91 | 316SS | 46 | 8.00 | 2.014 | 1.006 | 0.067 | 0.247 | 29.43 | 13.8753 | 13.8753 | 0.0002 | 24.0 | 1.39E-05 | 1.24E-05 |
| Generic rf | 7-24-91 | 316SS | 47 | 8.00 | 2.022 | 2.011 | 0.069 | 0.256 | 56.78 | 14.1215 | 14.1212 | 0.0003 | 24.0 | 1.08E-05 | |
| Generic rf | 7-24-91 | 410SS | 21 | 7.70 | 2.023 | 1.003 | 0.059 | 0.253 | 29.03 | 13.9880 | 13.9875 | 0.0005 | 24.0 | 3.67E-05 | 2.94E-05 |
| Generic rf | 7-24-91 | 410SS | 22 | 7.70 | 2.012 | 1.005 | 0.060 | 0.254 | 28.98 | 13.7080 | 13.7077 | 0.0003 | 24.0 | 2.21E-05 | |
| Generic rf | 7-24-91 | I-718 | 37 | 8.60 | 2.011 | 1.003 | 0.063 | 0.246 | 29.13 | 16.1783 | 16.1780 | 0.0003 | 24.0 | 1.96E-05 | 2.94E-05 |
| Generic rf | 7-24-91 | I-718 | 38 | 8.60 | 2.019 | 1.002 | 0.063 | 0.243 | 29.23 | 16.0128 | 16.0122 | 0.0006 | 24.0 | 3.92E-05 | |
| Generic rf | 7-24-91 | HA188 | 83 | 9.70 | 1.016 | 1.007 | 0.127 | 0.245 | 18.48 | 35.9876 | 35.9875 | 0.0001 | 24.0 | 9.15E-06 | 1.75E-05 |
| Generic rf | 7-24-91 | HA188 | 84 | 9.70 | 2.007 | 1.002 | 0.127 | 0.245 | 32.84 | 35.9359 | 35.9354 | 0.0005 | 24.0 | 2.58E-05 | |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions in inches | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|--|-----------|-------------------|-------------------------------------|-------------------------------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| | | | | Length | Width | thick | | | | | | | |
| Generic rf | 7-24-91 | 17-4PH | 41 | 7.80 | 2.003 | 1.007 | 0.062 | 0.271 | 28.94 | 14.8022 | 14.8012 | 0.0010 | 24.0 |
| Generic rf | 7-24-91 | 17-4PH | 42 | 7.80 | 2.014 | 1.005 | 0.063 | 0.249 | 29.21 | 15.3070 | 15.3067 | 0.0003 | 24.0 |
| Regeneration with an additional 0.1xx MeSCN added | | | | | | | | | | | | | |
| Generic rf | 7-24-91 | Ni-S | 306 | 8.90 | 2.045 | 1.047 | 0.076 | 0.235 | 31.63 | 21.6460 | 20.6759 | 0.9701 | 1.0 |
| Generic rf | 7-24-91 | Ni-S | 320 | 8.90 | 2.049 | 1.046 | 0.076 | 0.238 | 31.65 | 21.9817 | 21.0424 | 0.9393 | 1.0 |
| Regeneration Test after additional 1 oz/gal nickel loading pH 10.65 | | | | | | | | | | | | | |
| Generic rf | 7-30-91 | Ni-S | 352 | 8.90 | 2.048 | 1.039 | 0.075 | 0.240 | 31.37 | 21.1506 | 20.4931 | 0.6575 | 1.0 |
| Generic rf | 7-30-91 | Ni-S | 392 | 8.90 | 2.034 | 1.037 | 0.074 | 0.239 | 31.06 | 20.6919 | 19.9989 | 0.6930 | 1.0 |
| Generic rf | 7-30-91 | Ni-P*** | 65 | 8.90 | 2.000 | 1.008 | 0.068 | 0.244 | 29.42 | 16.8830 | 16.8805 | 0.0025 | 2.0 |
| Generic rf | 7-30-91 | Ni-P*** | 68 | 8.90 | 2.019 | 1.008 | 0.069 | 0.234 | 29.79 | 17.0020 | 16.9984 | 0.0036 | 2.0 |
| Generic rf | 7-30-91 | Ni-P* | 141 | 8.90 | 2.017 | 1.015 | 0.076 | 0.235 | 30.35 | 18.8152 | 18.4134 | 0.4018 | 2.0 |
| Generic rf | 7-30-91 | Ni-P* | 162 | 8.90 | 2.024 | 1.012 | 0.076 | 0.236 | 30.38 | 18.7601 | 18.4636 | 0.2965 | 2.0 |
| Generic rf | 7-30-91 | C4340 | 3 | 7.84 | 2.007 | 0.989 | 0.063 | 0.250 | 28.68 | 15.0690 | 0.0002 | 24.0 | 2.16E-01 |
| Generic rf | 7-30-91 | C4340 | 4 | 7.84 | 2.008 | 0.989 | 0.063 | 0.253 | 28.68 | 15.1081 | 0.0002 | 24.0 | 5.70E-05 |
| Generic rf | 7-30-91 | D6AC | 46 | 8.20 | 2.003 | 0.992 | 0.082 | 0.248 | 29.84 | 20.0807 | 20.0803 | 0.0003 | 24.0 |
| Generic rf | 7-30-91 | D6AC | 53 | 8.20 | 1.970 | 0.996 | 0.081 | 0.245 | 29.44 | 20.3592 | 20.3587 | 0.0005 | 24.0 |
| Generic rf | 7-30-91 | 316SS | 46 | 8.00 | 2.014 | 1.004 | 0.067 | 0.247 | 29.43 | 13.8753 | 13.8749 | 0.0004 | 24.0 |
| Generic rf | 7-30-91 | 316SS | 47 | 8.00 | 2.022 | 2.011 | 0.069 | 0.256 | 56.78 | 14.1212 | 14.1209 | 0.0003 | 24.0 |
| Generic rf | 7-30-91 | 410SS | 21 | 7.70 | 2.023 | 1.003 | 0.059 | 0.253 | 29.03 | 13.9875 | 13.9866 | 0.0009 | 24.0 |
| Generic rf | 7-30-91 | 410SS | 22 | 7.70 | 2.012 | 1.005 | 0.060 | 0.254 | 28.98 | 13.7077 | 13.7066 | 0.0011 | 24.0 |
| Generic rf | 7-30-91 | I-718 | 37 | 8.60 | 2.011 | 1.003 | 0.063 | 0.246 | 29.13 | 16.1780 | 16.1780 | 0.0000 | 24.0 |
| Generic rf | 7-30-91 | I-718 | 38 | 8.60 | 2.019 | 1.002 | 0.063 | 0.243 | 29.23 | 16.0122 | -0.0012 | 0.0001 | 24.0 |
| Generic rf | 7-30-91 | HA188 | 83 | 9.70 | 1.016 | 1.007 | 0.127 | 0.245 | 18.48 | 35.9875 | 35.9867 | 0.0008 | 24.0 |
| Generic rf | 7-30-91 | HA188 | 84 | 9.70 | 2.007 | 1.002 | 0.127 | 0.245 | 32.84 | 35.9354 | 35.9367 | 0.0007 | 24.0 |
| Generic rf | 7-30-91 | 17-4PH | 41 | 7.80 | 2.003 | 1.007 | 0.062 | 0.271 | 28.94 | 14.8012 | 14.8005 | 0.0007 | 24.0 |
| Generic rf | 7-30-91 | 17-4PH | 42 | 7.80 | 2.014 | 1.005 | 0.063 | 0.249 | 29.21 | 15.3067 | 15.3061 | 0.0006 | 24.0 |

Alternative Metal Coatings Tested in Longevity Solution Temp 130F

| Generic rf | 7-29-91 | Ni-B | N/A | 8.90 | 2.678 | 1.261 | 0.013 | 0.400 | 42.83 | 5.4101 | 4.0182 | 1.3919 | 1.0 | |
|------------|---------|--------|-----|------|-------|-------|-------|-------|-------|---------|---------|---------|-------------|----------|
| Generic rf | 7-29-91 | NiBron | N/A | 8.90 | 4.000 | 1.015 | 0.037 | 0.199 | 55.12 | 19.2099 | 18.1954 | 1.0145 | 1.44E+00 ** | |
| Generic rf | 8-14-91 | Ti | N/A | 4.50 | 1.012 | 0.563 | 0.025 | 0.000 | 8.36 | 1.8067 | 1.8068 | -0.0001 | 8.14E-01 | |
| Generic rf | 8-14-91 | Ti | N/A | 4.50 | 0.995 | 0.545 | 0.025 | 0.000 | 8.00 | 1.7232 | 1.7233 | -0.0001 | 4.36E-05 | |
| Generic rf | 8-14-91 | Cr | 33 | 7.20 | 2.057 | 1.040 | 0.075 | 0.243 | 31.51 | 19.5751 | 19.5759 | -0.0008 | 4.56E-05 | |
| Generic rf | 8-14-91 | Cr | 52 | 7.20 | 2.055 | 1.041 | 0.075 | 0.244 | 31.51 | 19.4436 | 19.4442 | -0.0006 | 5.78E-05 | |
| | | | | | | | | | | | | | 24.0 | 4.34E-05 |

** Denotes minimum stripping rate since all coating was removed during the test

APPENDIX F

**STRIPPING RATE DATA FOR JAR TESTS USED IN THE DEVELOPMENT OF
A GENERIC ELECTROLESS NICKEL STRIPPER**

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions length width thick | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|--|--|--|--|---------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| Electroless Nickel Stripping Tests | | | | | | | | | | | |
| Formulation #1 | Gly + EN | Glycine (1.5M), Na2CO3 (1.0M) | Temp 130F | Volume 220ml, Na m-NBS (10Xw), and NH4SCN (0.1M) | Magnetic stirring | | | | | | |
| Gly sol | 4-18-91 | Ni-P | 8.90 | 2.025 | 1.015 | 0.076 | 0.234 | 30.48 | 19.1277 | 18.8964 | 0.2313 |
| Gly sol | 4-18-91 | Ni-P | 9.4 | 2.023 | 1.017 | 0.076 | 0.234 | 30.51 | 19.1802 | 18.9601 | 0.2201 |
| Gly sol | 4-18-91 | Ni-S | 377 | 8.90 | 2.050 | 1.058 | 0.087 | 0.233 | 32.68 | 23.9408 | 0.4046 |
| Gly sol | 4-18-91 | Ni-S | 380 | 8.90 | 2.041 | 1.042 | 0.084 | 0.235 | 31.92 | 22.1985 | 0.3692 |
| Gly sol | 4-18-91 | C4340 | 2 | 7.84 | 2.000 | 1.026 | 0.062 | 0.250 | 29.51 | 15.3823 | 0.0005 |
| Gly sol | 4-18-91 | C4340 | 3 | 7.84 | 2.003 | 1.025 | 0.062 | 0.250 | 29.53 | 15.4487 | 0.0000 |
| Formulation #2 | Citric Acid | (0.5M) | NaOH (1.4M), Na m-NBS (10Xw), and NH4SCN (0.5M), and NH4SCN (0.1M) | | | | | | | | |
| Cit sol | 4-18-91 | Ni-P | 178 | 8.90 | 2.025 | 1.009 | 0.075 | 0.235 | 30.25 | 18.6842 | 0.1160 |
| Cit sol | 4-18-91 | Ni-P | 211 | 8.90 | 2.021 | 1.012 | 0.075 | 0.236 | 30.27 | 18.9682 | 0.1898 |
| Cit sol | 4-18-91 | Ni-S | 524 | 8.90 | 2.050 | 1.058 | 0.085 | 0.235 | 32.35 | 24.0120 | 0.1685 |
| Cit sol | 4-18-91 | Ni-S | 558 | 8.90 | 2.056 | 1.045 | 0.083 | 0.236 | 32.15 | 23.1134 | 0.1009 |
| Cit sol | 4-18-91 | C4340 | 4 | 7.84 | 1.981 | 1.023 | 0.062 | 0.250 | 29.17 | 15.1843 | 0.0001 |
| Cit sol | 4-18-91 | C4340 | 6 | 7.84 | 2.012 | 1.023 | 0.062 | 0.250 | 29.60 | 15.5560 | 0.0004 |
| Formulation #3 | With EN | NaSCN (1M) | NaOH (1.4M), Na m-NBS (10Xw), Borax (0.1M), EN (2.5Xv) | | | | | | | | |
| Form #3a | 5-3-91 | Ni-P | 123 | 8.90 | 2.018 | 1.010 | 0.074 | 0.238 | 30.11 | 19.1376 | 18.7686 |
| Form #3a | 5-3-91 | Ni-P | 257 | 8.90 | 2.021 | 1.012 | 0.073 | 0.241 | 30.13 | 19.0334 | 18.6911 |
| Form #3a | 5-3-91 | Ni-S | 387 | 8.90 | 2.036 | 1.032 | 0.079 | 0.242 | 31.24 | 21.0696 | 0.4875 |
| Form #3a | 5-3-91 | Ni-S | 521 | 8.90 | 2.048 | 1.052 | 0.080 | 0.239 | 32.03 | 24.0826 | 0.5725 |
| Form #3a | 5-3-91 | C4340 | 18 | 7.84 | 1.986 | 1.020 | 0.060 | 0.256 | 29.01 | 15.2726 | 0.0814 |
| Form #3a | 5-3-91 | C4340 | 19 | 7.84 | 2.005 | 1.012 | 0.059 | 0.257 | 29.00 | 15.1061 | 0.0205 |
| Formulation #3 | With Glycine | (also known as RSH's formulation #4) (used solution) | | | | | | | | | |
| Form #3b | 5-3-91 | Ni-P | 170 | 8.90 | 2.005 | 1.009 | 0.072 | 0.241 | 29.77 | 18.4824 | 18.2174 |
| Form #3b | 5-3-91 | Ni-P | 172 | 8.90 | 2.014 | 1.010 | 0.073 | 0.243 | 29.97 | 18.5884 | 18.3251 |
| Form #3b | 5-3-91 | Ni-S | 386 | 8.90 | 2.048 | 1.046 | 0.082 | 0.240 | 31.99 | 23.1881 | 0.4399 |
| Form #3b | 5-3-91 | Ni-S | 557 | 8.90 | 2.046 | 1.034 | 0.078 | 0.242 | 31.38 | 21.5779 | 0.4014 |
| Form #3b | 5-3-91 | C4340 | 20 | 7.84 | 2.002 | 1.017 | 0.060 | 0.258 | 29.14 | 15.3329 | NA |
| Form #3b | 5-3-91 | C4340 | 21 | 7.84 | 1.982 | 1.030 | 0.060 | 0.259 | 29.20 | 15.3772 | NA |
| Formulation #3 | With both EN and Glycine (used solution) | | | | | | | | | | |
| Form #3ab | 5-6-91 | Ni-P | 170 | 8.90 | 2.005 | 1.009 | 0.072 | 0.241 | 29.77 | 18.2174 | 17.9310 |
| Form #3ab | 5-6-91 | Ni-S | 386 | 8.90 | 2.048 | 1.046 | 0.082 | 0.240 | 31.99 | 22.7482 | 0.3270 |
| Form #3ab | 5-6-91 | C4340 | 20 | 7.84 | 2.002 | 1.017 | 0.060 | 0.258 | 29.14 | 15.3329 | 0.0019 |
| Glycine stripper with 4%v EN and some acetone (used solution) | | | | | | | | | | | |
| Gly + EN | 5-6-91 | Ni-P | 172 | 8.90 | 2.014 | 1.010 | 0.073 | 0.243 | 29.97 | 18.3251 | 18.0264 |
| Gly + EN | 5-6-91 | Ni-S | 557 | 8.90 | 2.046 | 1.034 | 0.078 | 0.242 | 31.38 | 21.1765 | 0.5489 |
| Gly + EN | 5-6-91 | C4340 | 21 | 7.84 | 1.982 | 1.030 | 0.060 | 0.259 | 29.20 | 15.3772 | 0.0003 |
| Reformulation #1a | With EN | 20%v HNO3 (5Xv), Na m-NBS (10Xw), and NH4SCN (0.5M) | | | | | | | | | |
| Reform 1a | 5-9-91 | Ni-P | 12 | 8.90 | 2.032 | 1.040 | 0.076 | 0.235 | 31.25 | 18.6562 | 16.8813 |
| Reform 1a | 5-9-91 | Ni-S | 15 | 8.90 | 2.023 | 1.035 | 0.075 | 0.235 | 30.93 | 17.9918 | 16.3973 |
| Reform 1a | 5-9-91 | C4340 | 4 | 7.84 | 1.981 | 1.023 | 0.062 | 0.250 | 29.17 | 15.1843 | 0.0000 |
| Reform 1a | 5-9-91 | C4340 | 6 | 7.84 | 2.012 | 1.023 | 0.062 | 0.250 | 29.60 | 15.5559 | 0.0004 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions-----in inches----- | | | hole (cm ²) | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) |
|---|-----------|-------------------|-------------------------------------|--|-------|-----------|-------------------------|---------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|
| | | | | length | width | thickness | | | | | | | | |
| MetalX B-9 Full Strength (2.5 lb/gal) | | | | | | | | | | | | | | |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.021 | 1.021 | 0.074 | 0.237 | 30.45 | 18.7925 | 18.2446 | 0.5479 | 2.0 | 3.98E-01 | 3.65E-01 |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.030 | 1.011 | 0.075 | 0.238 | 30.36 | 18.7479 | 18.2920 | 0.4559 | 2.0 | 3.32E-01 | |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.058 | 1.051 | 0.086 | 0.235 | 32.53 | 24.2788 | 23.5679 | 0.7109 | 2.0 | 4.83E-01 | 5.12E-01 |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.056 | 1.033 | 0.084 | 0.234 | 31.89 | 23.0962 | 22.3156 | 0.7806 | 2.0 | 5.41E-01 | |
| MetalX B-9 Partial Strength (1.5 lb/gal) | | | | | | | | | | | | | | |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.013 | 1.012 | 0.074 | 0.236 | 30.10 | 18.5770 | 18.1688 | 0.4082 | 2.0 | 3.00E-01 | 3.11E-01 |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.025 | 1.015 | 0.074 | 0.237 | 30.35 | 18.8493 | 18.4063 | 0.4430 | 2.0 | 3.23E-01 | |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.072 | 1.037 | 0.081 | 0.236 | 32.04 | 21.6233 | 20.8994 | 0.7239 | 2.0 | 5.00E-01 | 4.89E-01 |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.053 | 1.050 | 0.085 | 0.234 | 32.38 | 23.4685 | 22.7691 | 0.6994 | 2.0 | 4.78E-01 | |
| MetalX B-9 Partial Strength (2.0 lb/gal) With Ethylenediamine (1% vol) added | | | | | | | | | | | | | | |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.029 | 1.012 | 0.076 | 0.236 | 30.45 | 19.0866 | 18.4795 | 0.6071 | 2.0 | 4.41E-01 | 4.38E-01 |
| B-9 | 4-25-91 | Ni-P | 8.90 | 2.032 | 1.012 | 0.076 | 0.235 | 30.49 | 19.1926 | 18.5936 | 0.5990 | 2.0 | 4.34E-01 | |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.055 | 1.047 | 0.085 | 0.235 | 32.32 | 22.9683 | 22.0718 | 0.8965 | 2.0 | 6.14E-01 | 6.46E-01 |
| B-9 | 4-25-91 | Ni-S | 8.90 | 2.040 | 1.047 | 0.083 | 0.236 | 31.98 | 22.5328 | 21.5525 | 0.9803 | 2.0 | 6.78E-01 | |
| Gen Ni-P Stripper Testing - all jar tests (250 ml. volume) | | | | | | | | | | | | | | |
| Formulation: 1.0M Na3Citrate + 5% EN + 0.5% H2O2 | | | | | | | | | | | | | | |
| Gen Ni-P | 7-3-91 | Ni-P | 2 | 8.90 | 2.024 | 1.013 | 0.076 | 0.235 | 30.41 | 19.0519 | 19.0364 | 0.0155 | 1.0 | 2.25E-02 |
| Gen Ni-P | 7-3-91 | Ni-P | 9 | 8.90 | 2.023 | 1.013 | 0.075 | 0.235 | 30.33 | 18.9145 | 18.9002 | 0.0143 | 1.0 | 2.09E-02 |
| Formulation: 1.0M Na3Citrate + 5% EN + 0.5% H2O2 with 0.25g NASCN and 1 mL H2O2 (50%) added | | | | | | | | | | | | | | |
| Gen Ni-P | 7-3-91 | Ni-P | 14 | 8.90 | 2.027 | 1.016 | 0.075 | 0.236 | 30.47 | 18.7723 | 18.7110 | 0.0613 | 2.0 | 4.45E-02 |
| Gen Ni-P | 7-3-91 | Ni-P | 18 | 8.90 | 2.012 | 1.016 | 0.076 | 0.235 | 30.32 | 19.0365 | 18.9574 | 0.0791 | 1.0 | 1.15E-01 |
| Gen Ni-P | 7-3-91 | Ni-P* | 111 | 8.90 | 2.031 | 1.014 | 0.072 | 0.241 | 30.27 | 18.3236 | 18.3164 | 0.0072 | 1.0 | 1.05E-02 |
| Formulation: Above with 0.01M CuSO ₄ added | | | | | | | | | | | | | | |
| Gen Ni-P | 7-4-91 | Ni-P | 2 | 8.90 | 2.024 | 1.013 | 0.076 | 0.235 | 30.41 | 19.0364 | 19.0354 | 0.0010 | 1.0 | 1.45E-03 |
| Gen Ni-P | 7-4-91 | Ni-P | 9 | 8.90 | 2.023 | 1.013 | 0.075 | 0.235 | 30.33 | 18.9005 | 18.8997 | 0.0008 | 1.0 | 1.17E-03 |
| Formulation: Previous copper solution with 2 mL H2O2 (50%) added | | | | | | | | | | | | | | |
| Gen Ni-P | 7-4-91 | Ni-P | 14 | 8.90 | 2.027 | 1.016 | 0.075 | 0.236 | 30.47 | 18.7112 | 18.6526 | 0.0586 | 1.0 | 8.51E-02 |
| Gen Ni-P | 7-4-91 | Ni-P | 18 | 8.90 | 2.012 | 1.016 | 0.076 | 0.235 | 30.32 | 18.9574 | 18.8902 | 0.0672 | 1.0 | 9.80E-02 |
| Formulation: Previous solution with 0.1% NaSCN | | | | | | | | | | | | | | |
| Gen Ni-P | 7-4-91 | Ni-P | 14 | 8.90 | 2.027 | 1.016 | 0.075 | 0.236 | 30.47 | 18.6526 | 18.5333 | 0.0193 | 1.0 | 2.80E-02 |
| Gen Ni-P | 7-4-91 | Ni-P | 18 | 8.90 | 2.012 | 1.016 | 0.076 | 0.235 | 30.32 | 18.8902 | 18.8661 | 0.0241 | 1.0 | 3.52E-02 |
| Formulation: 20% EN + 2% HNO ₃ (conc) + Ce(NH ₄) ₄ (SO ₄) ₄ (later filtered out as CeO ₂) + 0.1% NaSCN + 1 mL H2O2 (50%) | | | | | | | | | | | | | | |
| Gen Ni-P | 7-4-91 | Ni-P | 2 | 8.90 | 2.024 | 1.013 | 0.076 | 0.235 | 30.41 | 19.0052 | 18.9402 | 0.0650 | 1.0 | 9.46E-02 |
| Gen Ni-P | 7-4-91 | Ni-P | 9 | 8.90 | 2.023 | 1.013 | 0.075 | 0.235 | 30.33 | 18.8710 | 18.8100 | 0.0610 | 1.0 | 8.90E-02 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions length width thick | Area hole (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (mil/hr) | Average S.R. (mil/hr) |
|---|-----------|-------------------|-------------------------------------|---|------------------------------|----------------------|--------------------|---------------------|--------------------|-------------------------|-----------------------|
| Formulation: Previous copper solution with 1%w NaSCN and 1 mL H2O2 (50%) added | | | | | | | | | | | |
| Gen Ni-P | 7-4-91 | Ni-P | 14 | 8.90 | 2.027 | 1.016 | 0.075 | 0.236 | 30.47 | 18.6333 | 18.5805 |
| Gen Ni-P | 7-4-91 | Ni-P | 18 | 8.90 | 2.012 | 1.016 | 0.076 | 0.235 | 30.32 | 18.8661 | 0.0486 |
| Formulation: 0.8M Na2.5(citrate) + 5%v EN + 5%w Na m-NBS pH about 11 | | | | | | | | | | | |
| Gen Ni-P | 7-5-91 | Ni-P | 2 | 8.90 | 2.026 | 1.013 | 0.076 | 0.235 | 30.41 | 18.9402 | 0.2114 |
| Gen Ni-P | 7-5-91 | Ni-P | 9 | 8.90 | 2.023 | 1.013 | 0.075 | 0.235 | 30.33 | 18.8100 | 0.4495 |
| Gen Ni-P | 7-5-91 | Ni-P* | 111 | 8.90 | 2.031 | 1.014 | 0.072 | 0.241 | 30.27 | 18.3164 | 0.0051 |
| Formulation: above with 2 mL H2O2 (50%) [sol. started to fizz after 5 mins] | | | | | | | | | | | |
| Gen Ni-P | 7-5-91 | Ni-P | 14 | 8.90 | 2.027 | 1.016 | 0.075 | 0.236 | 30.47 | 18.5805 | 0.1675 |
| Gen Ni-P | 7-5-91 | Ni-P | 18 | 8.90 | 2.012 | 1.016 | 0.076 | 0.235 | 30.32 | 18.8175 | 0.4469 |
| Formulation: 20%v EN solution with 5%w Na m-NBS added | | | | | | | | | | | |
| Gen Ni-P | 7-5-91 | Ni-P | 32 | 8.90 | 2.040 | 1.015 | 0.074 | 0.235 | 30.57 | 18.7617 | 18.6358 |
| Gen Ni-P | 7-5-91 | Ni-P | 33 | 8.90 | 2.043 | 1.012 | 0.076 | 0.235 | 30.65 | 19.2006 | 19.0553 |
| Gen Ni-P Stripper Testing - all jar tests (250mL vol., 130F, magnetic stirring) | | | | | | | | | | | |
| Formulation #1: 15%v EN + 10%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.19 | | | | | | | | | | | |
| Gen Ni-P | 8-1-91 | Ni-P* | 29 | 8.90 | 2.015 | 1.020 | 0.075 | 0.236 | 30.41 | 18.7998 | 0.0586 |
| Gen Ni-P | 8-1-91 | Ni-P* | 40 | 8.90 | 2.021 | 1.014 | 0.075 | 0.235 | 30.33 | 18.8094 | 0.0686 |
| Formulation #2: 20%v EN + 10%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.53 | | | | | | | | | | | |
| Gen Ni-P | 8-1-91 | Ni-P* | 52 | 8.90 | 2.015 | 1.013 | 0.075 | 0.234 | 30.23 | 18.6330 | 0.0558 |
| Gen Ni-P | 8-1-91 | Ni-P* | 62 | 8.90 | 2.020 | 1.014 | 0.076 | 0.234 | 30.38 | 19.1116 | 0.0562 |
| Retry of Formulation #2: 20%v EN + 10%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.53 | | | | | | | | | | | |
| Gen Ni-P | 8-2-91 | Ni-P* | 81 | 8.90 | 2.019 | 1.013 | 0.076 | 0.235 | 30.34 | 19.0743 | 18.9862 |
| Gen Ni-P | 8-2-91 | Ni-P* | 223 | 8.90 | 2.017 | 1.015 | 0.074 | 0.236 | 30.24 | 18.6465 | 18.5937 |
| Formulation #3: 15%v EN + 15%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.27 | | | | | | | | | | | |
| Gen Ni-P | 8-1-91 | Ni-P* | 235 | 8.90 | 2.021 | 1.013 | 0.074 | 0.237 | 30.24 | 18.4863 | 17.5715 |
| Gen Ni-P | 8-1-91 | Ni-P* | 241 | 8.90 | 2.019 | 1.013 | 0.074 | 0.236 | 30.21 | 18.3220 | 17.2762 |
| Retry Formulation #3: 15%v EN + 15%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.27 | | | | | | | | | | | |
| Gen Ni-P | 8-5-91 | Ni-P* | 103 | 8.90 | 2.037 | 1.013 | 0.073 | 0.236 | 30.41 | 18.3791 | 17.8047 |
| Gen Ni-P | 8-5-91 | Ni-P* | 132 | 8.90 | 2.022 | 1.012 | 0.075 | 0.235 | 30.29 | 18.7078 | 18.1332 |
| 2nd Formulation #3: 15%v EN + 15%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 9.58 | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 52 | 8.90 | 2.015 | 1.013 | 0.075 | 0.234 | 30.23 | 18.5772 | 18.5143 |
| Gen Ni-P | 8-6-91 | Ni-P* | 62 | 8.90 | 2.020 | 1.014 | 0.076 | 0.234 | 30.38 | 19.0562 | 0.0396 |
| Formulation #4: 15%v EN + 10%w Na m-NBS + 11%v HNO3 + 0.1%w NaSCN pH 9.58 | | | | | | | | | | | |
| Gen Ni-P | 8-1-91 | Ni-P* | 272 | 8.90 | 2.021 | 1.011 | 0.075 | 0.236 | 30.25 | 18.4477 | 17.9083 |
| Gen Ni-P | 8-1-91 | Ni-P* | 13 | 8.90 | 2.017 | 1.013 | 0.074 | 0.236 | 30.19 | 18.4275 | 0.2228 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | Area hole (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) |
|--|-----------|-------------------|-------------------------------------|---------------------|-------|-------|------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|
| | | | | length | width | thick | | | | | | | |
| Formulation #5: 20%v EN + 15%w Na m-NBS + 9%v Na m-NBS + 0.1%w NaSCN pH 10.35 | | | | | | | | | | | | | |
| Gen Ni-P | 8-2-91 | Ni-P* | 103 | 8.90 | 2.037 | 1.013 | 0.073 | 0.236 | 30.41 | 18.4240 | 18.3791 | 0.0449 | 2.0 |
| Gen Ni-P | 8-2-91 | Ni-P* | 132 | 8.90 | 2.022 | 1.012 | 0.075 | 0.235 | 30.29 | 18.7490 | 18.7078 | 0.0412 | 2.0 |
| Formulation #6: 10%v EN + 15%w Na m-NBS + 5%v HNO3 + 0.1%w NaSCN pH 10.23 | | | | | | | | | | | | | |
| Gen Ni-P | 8-2-91 | Ni-P* | 144 | 8.90 | 2.018 | 1.013 | 0.075 | 0.235 | 30.26 | 18.7568 | 18.6869 | 0.0499 | 2.0 |
| Gen Ni-P | 8-2-91 | Ni-P* | 148 | 8.90 | 2.021 | 1.013 | 0.075 | 0.236 | 30.30 | 18.8188 | 18.7710 | 0.0678 | 2.0 |
| Formulation #7: 15%v EN + 15%w Na m-NBS + 5%v HNO3 + 0.1%w NaSCN pH 10.59 | | | | | | | | | | | | | |
| Gen Ni-P | 8-2-91 | Ni-P* | 173 | 8.90 | 2.021 | 1.013 | 0.075 | 0.235 | 30.30 | 18.8146 | 18.7877 | 0.0269 | 2.0 |
| Gen Ni-P | 8-2-91 | Ni-P* | 174 | 8.90 | 2.021 | 1.013 | 0.075 | 0.235 | 30.31 | 18.7440 | 18.6895 | 0.0545 | 2.0 |
| Retry Formulation #7: 15%v EN + 15%w Na m-NBS + 5%v Na m-NBS + 0.1%w NaSCN pH 10.59 | | | | | | | | | | | | | |
| Gen Ni-P | 8-5-91 | Ni-P* | 144 | 8.90 | 2.018 | 1.013 | 0.075 | 0.235 | 30.26 | 18.6869 | 18.6688 | 0.0181 | 2.0 |
| Gen Ni-P | 8-5-91 | Ni-P* | 148 | 8.90 | 2.021 | 1.013 | 0.075 | 0.235 | 30.31 | 18.7710 | 18.7586 | 0.0124 | 2.0 |
| Formulation #8: 15%v EN + 15%w Na m-NBS + 7%v HNO3 + 0.5%w NaSCN pH 10.25 | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 173 | 8.90 | 2.021 | 1.013 | 0.075 | 0.236 | 30.30 | 18.7877 | 18.7508 | 0.0369 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 223 | 8.90 | 2.017 | 1.015 | 0.074 | 0.236 | 30.24 | 18.5937 | 18.5398 | 0.0539 | 2.0 |
| Formulation #9: 5%v EN + 15%w Na m-NBS + 2.5%v HNO3 + 0.1%w NaSCN pH 10.15 | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 29 | 8.90 | 2.015 | 1.020 | 0.075 | 0.236 | 30.41 | 18.7412 | 18.7042 | 0.0370 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 40 | 8.90 | 2.021 | 1.014 | 0.075 | 0.235 | 30.33 | 18.7408 | 18.7008 | 0.0400 | 2.0 |
| 2nd Formulation #3: 15%v EN + 15%w Na m-NBS + 7%v HNO3 + 0.1%w NaSCN pH 10.27 | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 52 | 8.90 | 2.015 | 1.013 | 0.075 | 0.234 | 30.23 | 18.5772 | 18.5143 | 0.0629 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 62 | 8.90 | 2.020 | 1.014 | 0.076 | 0.234 | 30.38 | 19.0562 | 19.0166 | 0.0396 | 2.0 |
| 2nd Formulation #3, Retry after coupon conditioning with Al/NH₃ | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 52 | 8.90 | 2.015 | 1.013 | 0.075 | 0.234 | 30.23 | 18.5140 | 18.4538 | 0.0602 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 62 | 8.90 | 2.020 | 1.014 | 0.076 | 0.234 | 30.38 | 19.0161 | 18.9612 | 0.0549 | 2.0 |
| 2nd Formulation #3, Retry after coupon conditioning with Al/NH₃ | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 237 | 8.90 | 2.017 | 1.011 | 0.074 | 0.236 | 30.13 | 18.2708 | 17.8739 | 0.3969 | 1.5 |
| Gen Ni-P | 8-6-91 | Ni-P** | 82 | 8.90 | 2.012 | 1.010 | 0.073 | 0.237 | 29.97 | 18.0277 | 18.0259 | 0.0018 | 1.5 |
| 2nd Formulation #3, Retry using Niplex tested coupons | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 6 | 8.90 | 2.016 | 1.013 | 0.074 | 0.236 | 30.17 | 18.7124 | 17.6912 | 1.0212 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 184 | 8.90 | 2.015 | 1.012 | 0.073 | 0.236 | 30.07 | 18.4496 | 17.5355 | 0.9141 | 2.0 |
| Redone Tests using 250 mL vultures and refurbished Niplex 100 coupons | | | | | | | | | | | | | |
| Formulation #1 | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 41 | 8.90 | 2.015 | 1.016 | 0.072 | 0.238 | 30.11 | 17.9215 | 17.6421 | 0.2794 | 2.0 |
| Gen Ni-P | 8-6-91 | Ni-P* | 114 | 8.90 | 2.022 | 1.007 | 0.072 | 0.239 | 29.96 | 17.9232 | 17.5812 | 0.3420 | 2.0 |

| Stripper | Test Date | Coupon Material # | Coupon Density (g/cm ³) | Unmasked Dimensions | | | | Surface Area (cm ²) | Initial Mass (grams) | Final Mass (grams) | Change Mass (grams) | Total Time (hours) | Stripping Rate (ml/hr) | Average S.R. (ml/hr) |
|--|-----------|-------------------|-------------------------------------|---------------------|-------|-------|-------|---------------------------------|----------------------|--------------------|---------------------|--------------------|------------------------|----------------------|
| | | | | length | width | thick | hole | | | | | | | |
| Formulation #2 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 168 | 8.90 | 2.018 | 1.009 | 0.072 | 0.237 | 29.97 | 17.9690 | 17.6144 | 0.3546 | 2.0 | 2.62E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 217 | 8.90 | 2.019 | 1.008 | 0.073 | 0.238 | 30.01 | 18.1256 | 17.5988 | 0.5268 | 2.0 | 3.88E-01 |
| 2nd Formulation #3, Retry using Niptex tested coupons | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 6 | 8.90 | 2.016 | 1.013 | 0.074 | 0.236 | 30.17 | 18.7124 | 17.6912 | 1.0212 | 2.0 | 7.49E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 184 | 8.90 | 2.015 | 1.012 | 0.073 | 0.236 | 30.07 | 18.4496 | 17.5355 | 0.9141 | 2.0 | 6.72E-01 |
| Formulation #4 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 232 | 8.90 | 2.013 | 1.008 | 0.072 | 0.240 | 29.86 | 17.7801 | 17.1810 | 0.5991 | 2.0 | 4.44E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 246 | 8.90 | 2.014 | 1.007 | 0.072 | 0.239 | 29.85 | 17.6421 | 17.1252 | 0.5169 | 2.0 | 3.83E-01 |
| Formulation #5 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 56 | 8.90 | 2.020 | 1.011 | 0.072 | 0.238 | 30.04 | 18.1766 | 17.9851 | 0.1915 | 2.0 | 1.41E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 68 | 8.90 | 2.017 | 1.010 | 0.073 | 0.237 | 30.04 | 18.2608 | 18.0764 | 0.1844 | 2.0 | 1.36E-01 |
| Formulation #6 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 74 | 8.90 | 2.018 | 1.010 | 0.074 | 0.236 | 30.12 | 18.4065 | 18.2638 | 0.1427 | 2.0 | 1.05E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 78 | 8.90 | 2.016 | 1.011 | 0.075 | 0.236 | 30.18 | 18.6938 | 18.2894 | 0.4044 | 2.0 | 2.96E-01 |
| Formulation #7 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 130 | 8.90 | 2.015 | 0.987 | 0.072 | 0.239 | 29.32 | 17.3378 | 17.0186 | 0.3192 | 2.0 | 2.41E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 192 | 8.90 | 1.999 | 1.013 | 0.072 | 0.238 | 29.80 | 17.8453 | 17.3542 | 0.4911 | 2.0 | 3.64E-01 |
| Formulation #8 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 205 | 8.90 | 2.001 | 1.010 | 0.072 | 0.238 | 29.75 | 17.7963 | 17.4836 | 0.3127 | 2.0 | 2.32E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 276 | 8.90 | 2.009 | 1.007 | 0.071 | 0.237 | 29.73 | 17.5397 | 17.3316 | 0.2181 | 2.0 | 1.62E-01 |
| Formulation #9 | | | | | | | | | | | | | | |
| Gen Ni-P | 8-6-91 | Ni-P* | 247 | 8.90 | 2.017 | 1.014 | 0.073 | 0.238 | 30.14 | 18.2086 | 18.0693 | 0.1393 | 2.0 | 1.02E-01 |
| Gen Ni-P | 8-6-91 | Ni-P* | 250 | 8.90 | 2.014 | 1.007 | 0.072 | 0.239 | 29.85 | 17.7166 | 17.5600 | 0.1566 | 2.0 | 1.16E-01 |